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Information Summaries

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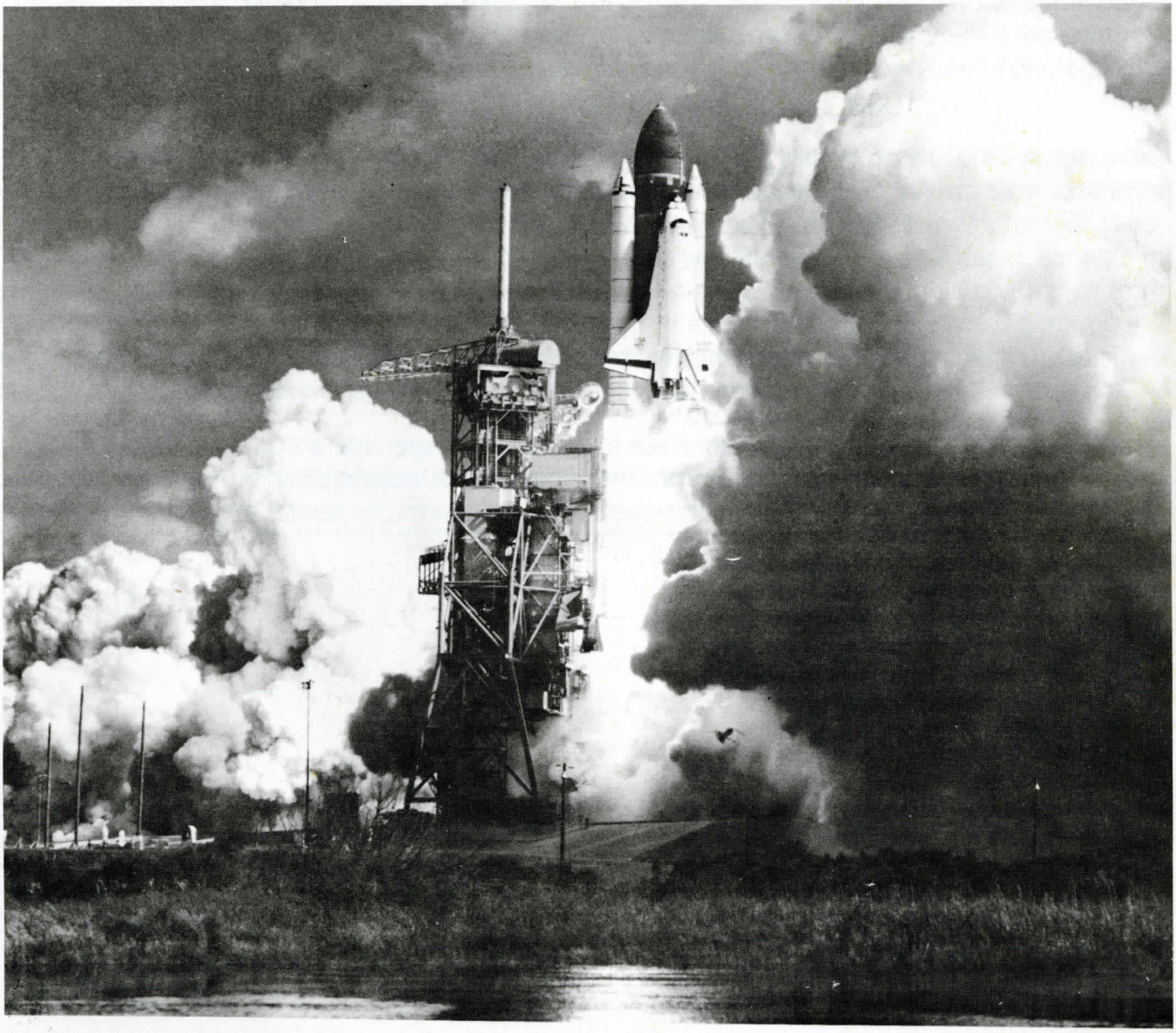
Space Shuttle Mission Summary

The First Decade: 1981 - 1990



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Introduction

This summary highlights the first ten years of Space Shuttle flights. From April 1981 through December 1990, 38 Space Shuttles lifted off from Launch Complex 39 at Kennedy Space Center. The first 24 flights demonstrated the versatility of the Shuttle concept. Numerous commercial communications satellites were deployed, errant spacecraft were rescued, detailed experiments were conducted using the Shuttle as an orbiting laboratory, and dazzling and useful photographs of the Earth were taken by astronauts circling high above.

The 25th liftoff, Mission 51-L in January 1986, ended tragically with the loss of crew and vehicle. After a top-to-bottom review of management, policies and procedures, followed by extensive hardware modifications and exhaustive testing, NASA resumed Shuttle flights in September 1988. The return to flight demonstrated that the Space Shuttle was indeed a national asset, capable of providing invaluable returns for the American taxpayer's dollar. In the 13 flights conducted from 1988 through 1990, three interplanetary explorers were sent on extended journeys through the solar system, Earth-orbiting satellites were deployed in a quest for new knowledge about the blue planet, and additional flights were conducted for the Department of Defense.

Only the most pertinent and important details of each mission are provided here, including a brief description of the payloads and experiments performed in orbit. Launch, landing, and mission duration numbers are based on Johnson Space Center documentation.

Space Shuttle Orbiter Fleet*

1981-1990

Vehicle	Name	Delivery Date	First Flight	Total Flights
OV-099	Challenger	July 1982	April 4, 1983	10
	[OV-099 was lost following its 10th liftoff in 1986]			
OV-102	Columbia	March 1979	April 12, 1981	10
OV-103	Discovery	November 1983	August 30, 1984	11
OV-104	Atlantis	April 1985	October 3, 1985	7

*Endeavour (OV-105), the replacement for Challenger, arrived at KSC in May 1991.

1981

The first four Shuttle missions formed the Orbital Flight Test Program, after which all subsequent missions were declared operational. Two flights were conducted in 1981, both using a painted external tank. The tank was left uncoated from STS-3 on, eliminating hundreds of pounds of unnecessary weight.

STS-1 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, Kennedy Space Center (KSC), Florida, at 7:00:03 a.m. EST on April 12, 1981, after a launch attempt on April 10 was scrubbed due to a timing skew in the orbiter general purpose computer system. Columbia remained in the Orbiter Processing Facility for 610 days after its arrival at KSC, due primarily to the replacement of the lightweight protective tile installed at the factory. This launch marked the first use of solid rockets on a manned vehicle, and the first time astronauts rode a new type of spaceship on its first flight. The primary mission objectives were a safe ascent into orbit, then a return to Earth for a landing on the orbiter's own wheels. Columbia landed on Runway 23, Edwards Air Force Base, California, on April 14, 1981, at 1:20:57 p.m. EST, after a mission duration of 2 days, 6 hours, 20 minutes, and 53 seconds. It had completed 36 orbits. Post-flight investigation revealed that Columbia had suffered some damage from an overpressure wave created by the solid rocket boosters at ignition, had lost 16 tiles, and had damaged 148. Columbia was otherwise in good condition.

Astronaut Robert Crippen floats in the weightlessness of microgravity inside the middeck area of Columbia on STS-1.

Crew. The crew members were John W. Young, commander; and Robert L. Crippen, pilot.

Payload and Experiments. Columbia carried the Development Flight Instrumentation (DFI) package, which contained strain sensors and measuring devices to report on spacecraft performance and the stresses encountered during launch, flight, and landing, but otherwise had no cargo.

STS-2 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 10:09:59 a.m. EST on November 12, 1981. The launch was delayed from a planned 7:30 a.m. liftoff by the need to replace one of Columbia's onboard data transmitting units. It had previously been delayed from a planned November 4 launch because of an apparent low reading on fuel cell oxygen tank pressures, followed by the changing of oil filters in two of the three auxiliary power units. This time Columbia went through the Orbiter Processing Facility in 103 days. Modifications to the water sound suppression system at the pad to absorb the overpressure wave from the solid rocket boosters were successful. This was the first time a manned spaceship was reflown with a second crew. During the flight a problem developed with one of the three fuel cells, and the mission duration was shortened from its planned five days. The crew nevertheless achieved 90% of the mission objectives. Columbia landed on Runway 23, Edwards AFB, on November 14, 1981, at 4:23:11 p.m. EST, after a mission duration of 2 days, 6 hours, 13 minutes, and 12 seconds. It had completed 36 orbits. Tile damage was minor.

Crew. The crew members were Joseph H. Engle, commander; and Richard H. Truly, pilot.

Payload and Experiments. Columbia again carried the DFI package of special sensors to report on the performance of the spacecraft and its various systems. The Canadian-built Remote Manipulator System arm (Canadarm) was operated by the crew in all its modes. The only payload was OSTA-1 (after the NASA "Office of Space and Terrestrial Applications"), a set of instruments mounted on a Spacelab pallet in the cargo bay. The experiments performed were in the areas of remote sensing of land resources, environmental quality, ocean conditions, and meteorological phenomena. One instrument, the Shuttle Imaging Radar-A (SIR-A), performed the unexpected feat of "looking through" several feet of dry sand in a desert region of North Africa to outline the original land surface, including dried riverbeds and rocky hills.

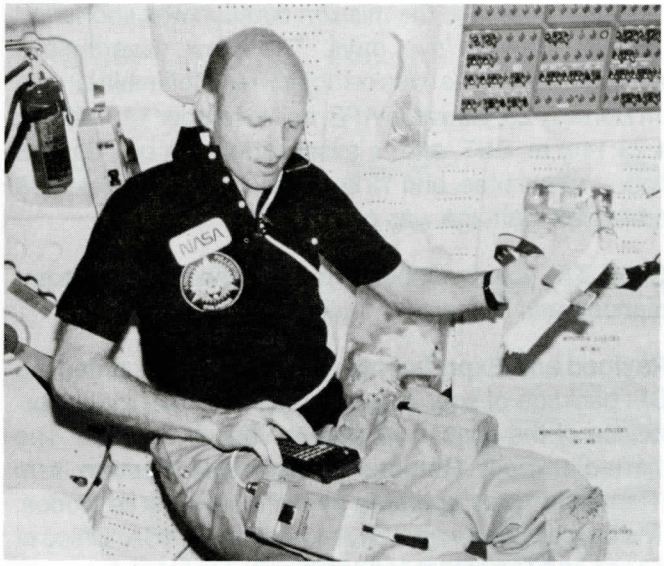
1982

Three Shuttle flights were conducted in 1982, including the first operational mission in November of that year. Initially, backup crews were named for each flight; this practice ceased after the third mission.

STS-3 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 11:00:00 a.m. EST on March 22, 1982. The launch had been delayed one hour by the failure of a heater on a nitrogen gas ground support line. Liftoff did occur on the originally scheduled day. Columbia's time in the Orbiter Processing Facility decreased to 70 days. The major mission goals were to perform further tests of the Canadarm and extensive thermal testing of the Columbia itself. The latter was accomplished by exposing the tail, nose and top to the Sun for varying periods of time, rolling it in between tests to stabilize temperatures over the entire body. The Canadarm tested satisfactorily, moving the Plasma Diagnostics Package experiment around the orbiter.

The planned seven-day mission was extended one day due to high winds at the back-up landing site, the



Astronaut Gordon Fullerton performs some intricate calculations using a hand-held calculator during the STS-3 mission.

Northrup Strip at White Sands, New Mexico. (The Edwards AFB primary landing site was too wet for a safe landing.) Columbia landed at Northrup Strip, March 30, 1982, at 11:04:46 a.m. EST, after a mission duration of 8 days, 0 hours, 4 minutes, and 46 seconds. A total of 36 tiles were lost and 19 damaged.

Crew. The crew members were Jack R. Lousma, commander; and C. Gordon Fullerton, pilot.

Payload and Experiments. In its cargo bay Columbia carried a Getaway Special test canister and a Spacelab pallet-mounted set of experiments for NASA's Office of Space Science and Applications called OSS-1. The latter obtained data on the near-Earth space environment, including the degree of contamination (gases, dust, outgassing particles) introduced by the orbiter itself. In the cabin middeck area were experiments on lignin formation in weightlessness, insect motion (the latter was the first Shuttle Student Involvement Project, or SSIP, to fly), a Continuous Flow Electrophoresis system to investigate separation of biological components, and a Monodisperse Latex Reactor experiment to produce micron-sized latex particles of uniform diameter. Columbia also flew the DFI package for the third time, and instruments to study catalytic surface effects, tile gap heating effects, and the dynamic, acoustic, and thermal environment around the orbiter.

STS-4 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 11:00:00 a.m. EDT on June 27, 1982. This was the first Space Shuttle to be launched on time and with no delays in schedule. Orbiter time in the Processing Facility was reduced to 42 days. The mission goals were to further test the flying, handling, and operating characteristics of the orbiter, to perform more exercises with the Canadarm, to conduct several scientific experiments in orbit, and to land at Edwards AFB for the first time on a concrete runway, one the same length as the Shuttle Landing Facility at KSC. Columbia was also scheduled for more thermal tests by exposure to the Sun in selected attitudes, but these plans were changed. Some hail that fell while Columbia was on the pad cut through the protective coating on the tiles and let some rainwater penetrate inside. In space the affected area on the underside was turned to the Sun, which vaporized the water and prevented further possible tile damage from freezing.

The only major problem on this mission was the loss of the two solid rocket booster casings. The main parachutes failed to function properly and the two casings hit the water at too high a velocity and sank. They were later found and examined by remote camera, but not recovered. Columbia landed on Runway 22, Edwards AFB, on July 4, 1982, at 12:09:31 p.m. EDT, after a mission duration of 7 days, 1 hour, 9 minutes and 31 seconds. President and Mrs. Reagan attended the landing and welcoming ceremonies.

Crew. The crew members were Thomas K. Mattingly, commander; and Henry W. Hartsfield Jr., pilot.

Payload and Experiments. In addition to a classified Air Force payload in the cargo bay, STS-4 carried the first Getaway Special — a series of nine experiments prepared by students from Utah State University. In the middeck area the astronauts operated a second and larger Continuous Flow Electrophoresis System and a second Monodisperse Latex Reactor experiment. They also performed a cloud-top lightning survey using handheld cameras, and took medical data on themselves for two student experiments. They operated the Canadarm again to move an instrument called the Induced Environmental Contamination Monitor around the orbiter in space, to gather data on any gases or particles being released by the orbiter.

STS-5 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 7:19:00 a.m. EST on November 11, 1982. This was the second Space Shuttle to be launched on time and with no delays in schedule. It was the first operational flight for the STS, with two commercial communications satellites, a number of experiments, and a four-astronaut crew. The latter became the "We Deliver" team when they successfully launched both satellites, ready for their trips into higher orbits. The only real problems during the mission occurred with the two spacesuits. The two mission specialists astronauts were scheduled to perform an extravehicular activity, but this had to be cancelled due to the malfunction of a ventilation motor in one suit and a pressure regulator in the other. Columbia landed on Runway 22, Edwards AFB, on November 16, 1982, at 9:33:26 a.m. EST, after a mission duration of 5 days, 2 hours, 14 minutes, and 26 seconds.

Crew. The crew members were Vance Brand, commander; Robert F. Overmyer, pilot; and Joseph P. Allen and William B. Lenoir, mission specialists.

Payload and Experiments. Two very similar communications satellites, SBS-3 and Anik C-3, built by Hughes Aircraft as part of the company's HS-376 series, were deployed for Satellite Business Systems and Telesat of Canada, respectively. Each was equipped with a Propulsion Assist Module (PAM) solid rocket motor, which fired automatically about 45 minutes after deployment and placed each satellite in a highly elliptical orbit. The company controllers of each later fired an onboard solid motor at apogee, and circularized the orbits. Both satellites were then checked out by their owners and entered into commercial service. Three SSIP experiments were conducted for student experimenters by the astronauts working in the middeck area, as was a third Monodisperse Latex Reactor test. The first of 25 Getaway Special experiments reserved by West Germany was conducted in the cargo bay, where X-rays of a molten mixture of mercury and gallium were taken to observe the effects of microgravity on the dispersion of mercury droplets into the gallium. A group of instruments provided additional information about Shuttle aerodynamics, atmospheric entry heating rates on different sections, the cargo bay environment, and other Shuttle properties.

1983

The Space Shuttle program notched a number of historic firsts in 1983, including the first space flights of an American woman and an African-American, as well as the first Shuttle flight of a European citizen and the European-built Spacelab. The Orbiter Challenger joined sister ship Columbia as a flight-tested vehicle, completing its first mission in April of 1983.

STS-6 Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 1:30:00 p.m. EST on April 4, 1983. This was the first launch of the second Space Shuttle orbiter, which was considered an operational vehicle on its initial flight. The originally scheduled launch date of January 20 was postponed twice, once for a hydrogen gas leak that required removal, repair and reinstallation of two of the Space Shuttle main engines and replacement of the third, and once because of payload contamination caused by a severe storm at the pad. The hydrogen leak was detected as a result of a 20-second Flight Readiness Firing of the main engines on December 18, 1982. This led to a second firing on January 25, 1983, which confirmed the leakage. As engine repairs were being performed, a severe storm with high winds breached the seals between the Payload Changeout Room in the Rotating Service Structure and their contact with the orbiter around the cargo bay. Particulate matter was blown inside. The payload had to be removed and returned to a checkout facility to be cleaned, and the Changeout Room and cargo bay were cleaned while it was away. On the new launch date Challenger lifted off on time, with no further problems. Its satellite payload was released into low Earth orbit as planned. The two mission specialists completed planned spacewalks using the new spacesuits. Challenger landed on Runway 22, Edwards AFB, on April 9, 1983, at 1:53:42 p.m. EST, after a mission duration of 5 days, 0 hours, 23 minutes, and 42 seconds.

Crew. The crew members were Paul J. Weitz, commander; Karol J. Bobko, pilot; and Donald H. Peterson and Story Musgrave, mission specialists.

Payload and Experiments. The primary payload for STS-6 was the first Tracking and Data Relay (TDRS) satellite. It weighed about 5,000 pounds, and was to be

injected into a geosynchronous transfer orbit by a 32,000-pound, two-stage solid propellant Inertial Upper Stage (IUS). The first stage fired as planned, but when the second stage fired at apogee, it cut off after 70 seconds of a planned 103-second burn. TDRS entered an unsatisfactory elliptical orbit. More propellant had been loaded aboard than was needed for its planned operational life, and this was used over the next several months to gradually circularize the orbit, using the spacecraft's own attitude control thrusters. The maneuver was successful, and TDRS-1 reached geosynchronous orbit and entered normal service. TDRS-1 was the first of three planned satellites to serve as orbiting relay and control stations for other spacecraft, making it possible to eliminate most of the system of ground tracking stations used prior to the Shuttle era. A TDRS can handle up to 300 million bits of information each second from a single user spacecraft. It operates in both Ku-band and S-band frequencies. The system of three satellites will be able to provide coverage for low-Earth orbit satellites (including the Space Shuttle) almost 100 percent of the time, compared with the 15 percent coverage now common for most such spacecraft.

STS-6 had three Getaway Specials in the cargo bay, one each on artificial snow formation, a packaged seed collection, and a composite metals experiment.

The first test of the new type of space suit designed for Shuttle astronauts was also completed with astronauts Musgrave and Peterson performing various tests in the cargo bay during four hours and 17 minutes of extravehicular activity. These tests went well. The Monodisperse Latex Reactor and Continuous Flow Electrophoresis experiments were also flown again and operated successfully.

STS-7 Mission

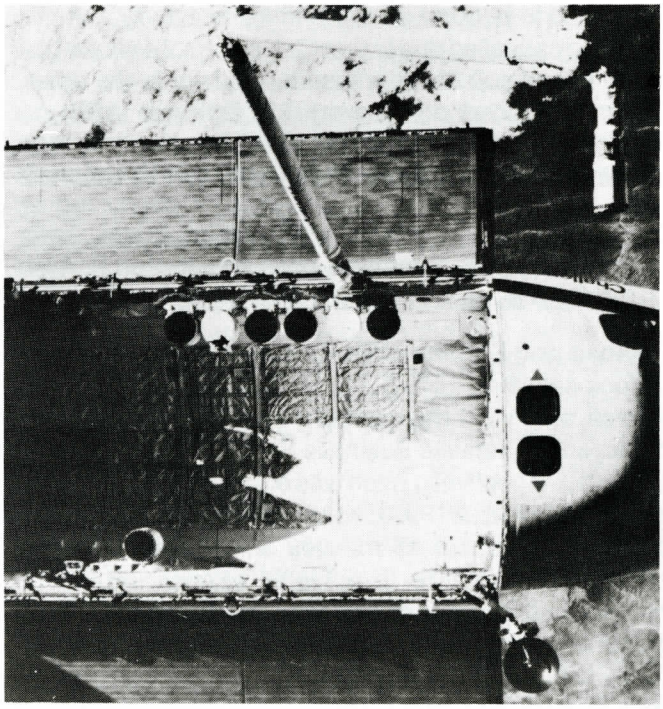
The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 7:33:00 a.m. EDT on June 18, 1983. The launch was on time and with no delays in schedule. This was the third operational flight of the Space Shuttle, and the second with a payload of two commercial communications satellites. It also featured a large variety of other items of cargo. This was the first STS launch with a crew of five astronauts, and the first flight of an American woman into space. The crew successfully deployed the two satellites, on the first and second days of the mission, and performed a series of other experiments. The Shuttle Ku-band antenna used with the TDRS satellite was successfully tested. The experiments among the seven Getaway Special canisters in the cargo bay that required start-and-stop operations were performed by the astronauts.

The Shuttle Pallet Satellite (SPAS-01) mounted in the cargo bay, which was built and supplied by the West German firm Messerschmitt-Bolkow-Blohm, was released into space by the Canadarm. Operating under its own power, it flew alongside Challenger for several hours, during which time a United States-supplied camera photographed Challenger against a background of Earth. The SPAS-01 was grappled twice by the Canadarm, then returned and locked into position in the cargo bay. Challenger was maneuvered away from and toward the SPAS-01 during these activities.

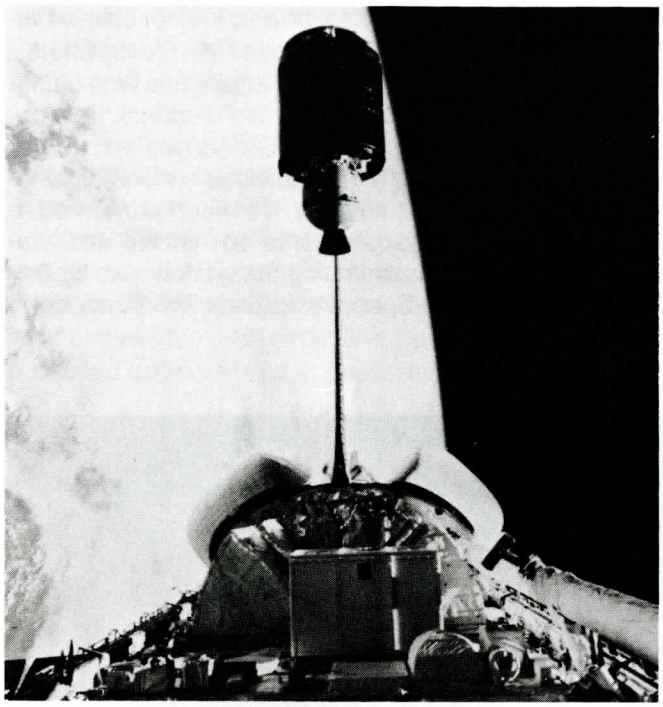
A second set of experiments called OSTA-2, supplied by the United States and the Federal Republic of Germany, was mounted on a special support structure in the cargo bay.

Astronaut Norman Thagard, a mission specialist and medical doctor, conducted medical tests in orbit on the problem of Space Adaptation Syndrome, the condition that often leads to nausea and sickness during the early hours of flight.

STS-7 was scheduled to land at the Shuttle Landing Facility at KSC, but rainy weather forced a landing at Edwards AFB. Challenger landed on Runway 23 on June 24, 1983, at 9:56:59 a.m. EDT, after a mission duration of 6 days, 2 hours, 23 minutes, and 59 seconds.



This view of the Orbiter Challenger above a mountainous region of the Earth, taken by the SPAS-01 platform floating above it during STS-7, shows the Remote Manipulator System "Canadarm" at the upper right center, extended up and back toward the crew compartment. The cylinders attached along the cargo bay walls are Get Away Special canisters.



One of two satellites deployed during STS-7, the Palapa-B geosynchronous communications satellite has just popped out of the open sunshield below as it climbs into space at a rate of three feet per second, while spinning at 50 rpm.

Crew. The crew members were Robert L. Crippen, commander; Frederick H. Hauck, pilot; and John M. Fabian, Sally K. Ride and Norman Thagard, mission specialists.

Payload and Experiments. The primary payload was two satellites built by Hughes Aircraft in its HS-376 series — Telesat's Anik C-2 (launched out of sequence behind Anik C-3 on STS-5) and Indonesia's Palapa B. The latter is the first of a second generation of communications satellites for PERUMTEL, the state-owned telecommunications company supplying modern communications to bind together the 3,000 islands of Indonesia. Both spacecraft were attached to PAM motors, which fired on schedule and successfully placed both into geosynchronous transfer orbits. Later, the onboard apogee motor of each was fired to circularize the orbit. Both entered service under the control of their owners.

Several Getaway Special canisters in the cargo bay held a wide variety of experiments, including ones on the effects of space on the social behavior of an ant colony in zero gravity, soldering operations, germination of radish seeds, and others. Ten experiments mounted on the SPAS-01 pallet performed research in the areas of forming metal alloys in microgravity, operating heat pipes, using a remote sensing scanner, utilizing a mass spectrometer to identify gases in the cargo bay, verifying a means of calibrating solar cells, and more.

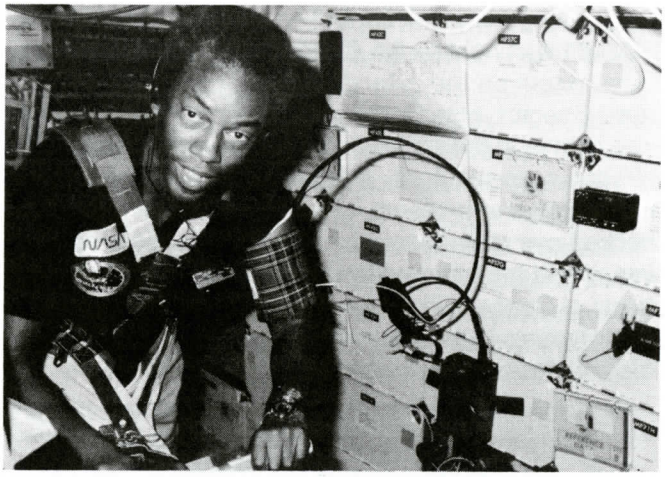
Challenger's small control rockets were fired while SPAS-01 was held by the Canadarm, to test the effects of movement on the extended arm. The Monodisperse Latex Reactor and Continuous Flow Electrophoresis experiments in the middeck area were operated by the astronauts as required. Astronaut Thagard measured fluid motion and pressure increase inside the head and checked eye movement and visual perception, both in himself and the other astronauts, gathering data on the effects of Space Adaptation Syndrome. A set of OSTA-2 experiments in the cargo bay were operated for materials processing experiments as planned.

Astronaut Sally Ride uses a screwdriver to release and clean an air filter during the STS-7 mission. Ride was the first American woman to go into space. The acronym on her T-shirt means "Thirty-five New Guys" for the group who trained with her to become astronauts.

STS-8 Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 2:32:00 a.m. EDT on August 30, 1983. This was the first night launch of a Space Shuttle. The time of launch was dictated by the tracking requirements for the primary payload, the INSAT 1B satellite being launched for India. It was the first spaceflight by an American black astronaut. It was the second launch where a mission specialist medical doctor conducted tests on himself and the other crew members to gather data on the cause of Space Adaptation Syndrome sickness. Ground operators performed some 20 tests of the TDRS satellite using the orbiter's S-band and Ku-band antenna systems, most without astronaut assistance. The relaying capabilities of the TDRS were being tested in preparation for the high data rate necessary to support the upcoming first Spacelab mission.

The INSAT 1B was deployed on the second day. The Challenger's nose was held away from the Sun for 14



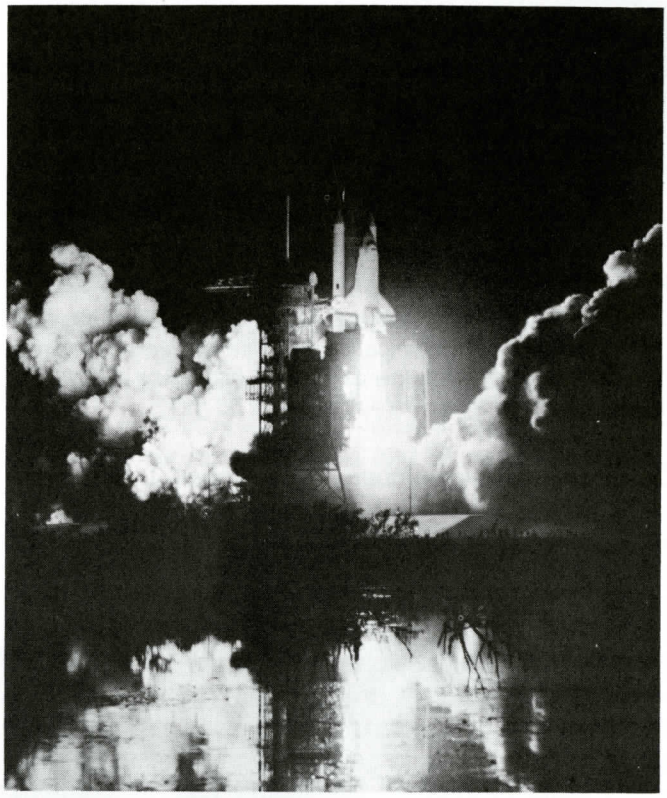
Astronaut Guion Bluford, who flew on STS-8 to become the first American black astronaut to perform a space flight, runs on a treadmill while wired to monitors that recorded the results of his exercise.

hours, to test the flight deck area in the extreme cold. The crew at this time filmed the performance of an experimental heat pipe mounted in the cargo bay. On the fourth day the Challenger dropped down to 139 miles altitude to perform a series of tests on the thin atomic oxygen there, as part of an effort to identify the cause of the "glow" that tends to surround parts of the orbiter at night. The Canadarm was exercised using a special 7,460-pound weight designed for that purpose. Due to the fact it was to be the first night landing, Challenger was brought down at Edwards AFB, landing on September 5, 1983, at 3:40:43 a.m. EDT, after a mission duration of 6 days, 1 hour, 8 minutes, and 43 seconds.

Crew. The crew members were Richard H. Truly, commander; Daniel C. Brandenstein, pilot; and Dale A. Gardner, Guion S. Bluford Jr. and William E. Thornton, mission specialists.

Payload and Experiments. The primary payload was the INSAT 1B spacecraft, a multipurpose satellite for India that can provide telecommunications, relay television signals to small home and community antennas in rural areas, and provide high-resolution infrared and visible light photographs of the complete Earth disk every 30 minutes for meteorological analysis and storm warnings. Formerly, a separate satellite was required for each of these major functions. The attached PAM-D stage fired automatically 45 minutes after deployment, placing the satellite in a geosynchronous transfer orbit. Two days later the onboard apogee motor was fired to circularize the orbit, after which the owner/controllers began checkout procedures.

Also in the cargo bay were 12 Getaway Special canisters, four containing experiments and eight holding STS-8 postal covers (plus more in two boxes mounted on an instrument panel, for a total of 260,000) for sale to the public after the flight. The Continuous Flow Electrophoresis System experiment was flown again, this time using live cells. An SSIP experiment in bio-feedback training was conducted on the astronauts. Six live rats were flown on the mission, in a new animal enclosure module being flight-tested for the first time. Dr. Thornton performed a series of biomedical experiments on himself and the other crew members, continuing the work began by Dr. Thagard on STS-7 on Space Adaptation Syndrome sickness.



Space Shuttle Challenger climbs into the darkened sky to begin the STS-8 mission, the only night launch of the Space Shuttle during the first three years. It also landed at night.

STS-9 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 11:00:00 a.m. EST on November 28, 1983. This was the first time six persons were launched into space on a single vehicle. The primary payload was Spacelab 1, a joint ESA/NASA venture that forms the major scientific investigation project associated with the Space Shuttle. A Spacelab rides in the cargo bay of an orbiter, and never flies free. This mission included two astronauts of a new type, payload specialists who had trained specifically to perform experiments in the Spacelab and were not NASA employees or career

astronauts. Although some instruments were carried in the middeck area they were also part of Spacelab 1; this mission was entirely devoted to Spacelab.

STS-9 verified the ability of Principal Investigators at the Payload Operations Control Center (recently installed at Johnson Space Center) to interact with astronauts in orbit on a "live" basis, greatly enhancing experimentation. This was also the first actual use of the high-capacity TDRS satellite to relay to its ground station a very large volume of data. The Spacelab experiments produced far more data than earlier payloads.

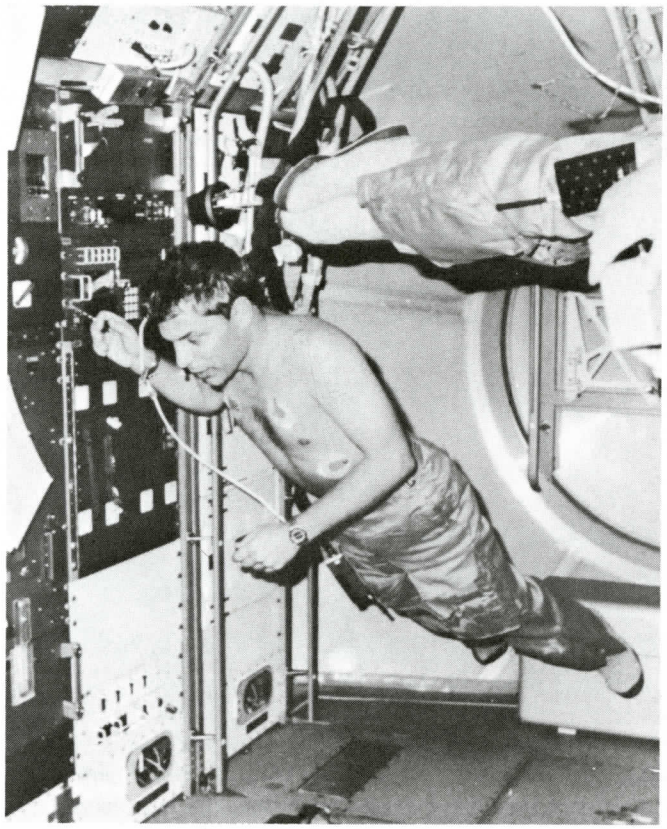
The six-man crew was divided into two teams for 24-hour continuous work. Young, Parker and Merbold (the latter the first European to fly on a Space Shuttle) formed the red team and Shaw, Garriott and Lichtenberg (the latter the first non-NASA American astronaut to fly in space) formed the blue team. The commander and pilot team members were usually stationed on the flight deck, while the mission specialist and payload specialist operated from inside the Spacelab. The work went so well the mission was extended from nine to ten days, becoming the longest STS mission to date.

Columbia landed at Edwards AFB on December 8, 1983, at 6:47:24 p.m. EST, after a delay of 7.5 hours caused by a malfunction of two of the Orbiter's general purpose computers and one inertial measurement unit. Several small fires were discovered in the tail section after landing, caused by leaks of hydrazine from the Auxiliary Power Units into the compartment. The mission duration was 10 days, 7 hours, 47 minutes, and 24 seconds.

Crew. The crew members were John W. Young, commander; Brewster H. Shaw Jr., pilot; Owen Garriott and Robert Parker, mission specialists; and Ulf Merbold of Germany and Byron Lichtenberg of the Massachusetts Institute of Technology, payload specialists.

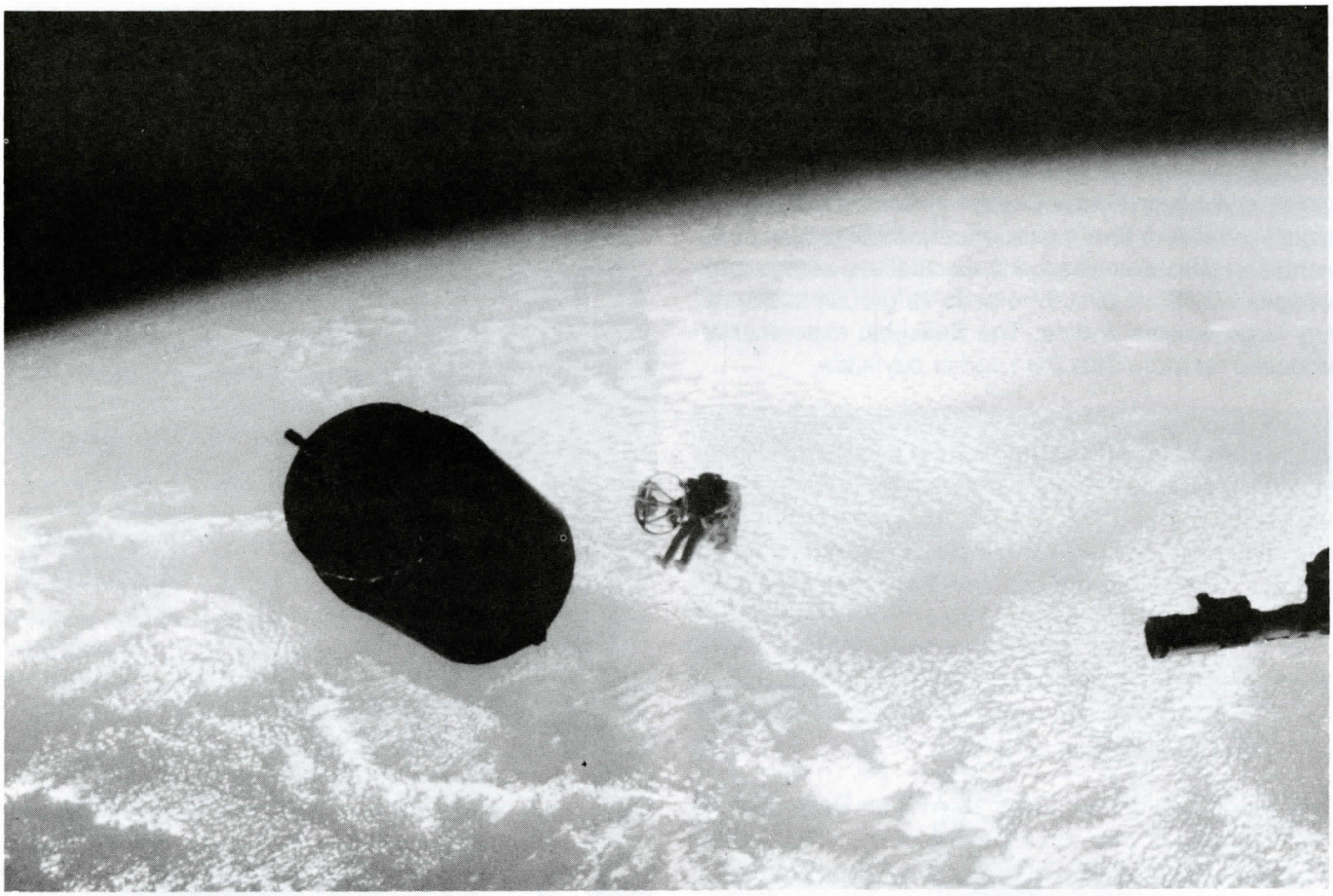
Payload and Experiments. Spacelab is an orbital laboratory and observation platform composed of cylindrical pressurized modules and U-shaped unpressurized pallets. The Spacelab remains physically inside the orbiter cargo bay, but is exposed to space when the cargo bay doors are open. The Spacelab elements can be arranged in various combinations and are reusable, most designed to be refurbished and relaunched as many of 50 times, over a lifespan of ten years.

The first Spacelab was funded by the European Space Agency, as a major contribution to the STS Program. A second set of Spacelab components was purchased by NASA. Spacelab 1 utilized one each core and experiment modules (combined and pressurized) and one pallet. The core module contained a window/viewport and the experiment module a cylindrical scientific airlock, the latter some three feet, three inches, in both length and diameter.



Mission specialist Robert Parker, wired for biomedical experiments with sensors attached to his torso, hovers inside the Spacelab 1 module during STS-9. Ulf Merbold's body can be seen at the upper right.

Most Spacelab missions are expected to be devoted to a single scientific discipline (e.g. astronomy, Earth resources, materials processing, etc.), but Spacelab 1 was a proof-of-concept flight and performed experiments in several areas. These included atmospheric and plasma physics, astronomy, solar physics, material sciences, technology, life sciences and Earth observations. The experiment payload was divided roughly in half by weight between ESA and NASA. The astronauts performed numerous experiments in all areas. A very large amount of data was accumulated. The essential assumptions of the Spacelab operating program were all proven in practice. These were: using non-NASA astronauts trained only as payload specialists; a scientific command center on the ground to provide close collaboration with the astronauts in orbit; the ability of TDRS to relay the data; and the ability of Spacelab to support complex experiments in all planned scientific areas.



Astronaut Dale A. Gardner flies his Manned Maneuvering Unit toward the spinning Westar VI satellite on the STS 51-A mission, holding a capture device called a "stinger" in front of him. Westar VI became one of the first two satellites to be recovered in space and returned to Earth for refurbishment and relaunching.

1984

The first Shuttle landing at KSC and the first untethered space walks occurred in 1984. Astronauts demonstrated the feasibility of refueling satellites in orbit, fixed one spacecraft in orbit and retrieved two others for repair and re-launch. Five flights were conducted, including the first by the Orbiter Discovery. Also started in 1984 was a new system for designating Shuttle missions to indicate year, launch site and order of the flight. The mission was identified by two digits and a letter, separated by a dash. The first digit indicated the government fiscal year the flight would be flown; the second from which launch site (1 for Kennedy Space Center or 2 for Vandenberg Air Force Base, Calif.), and the letter the chronological order of the flight within that particular year. Thus, for Mission 41-B, the "4" meant that it was scheduled to be conducted in 1984, the "1" that it would be from Kennedy Space Center, and the "B" that it would be the second flight of that year. Mission 61-C was planned as the third flight of 1986, again from KSC. The designation was retained even if the assigned order and year were not achieved.

STS 41-B Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 8:00:00 a.m. EST on February 3, 1984. This was the first launch of a Space Shuttle under the new numbering system. The primary mission goal was to deploy two commercial communications satellites, but 41-B also featured an ambitious set of experiments. These included the first untethered flights of astronauts using the new Manned Maneuvering Unit (MMU); the second flight of the West German space platform named SPAS, which had flown on STS-7 and so became the first spacecraft to be refurbished and flown on a second mission; the release of an inflated balloon, and two days of orbiter rendezvous maneuvers with the balloon as target; operations with the new Manipulator Foot Restraint that enables astronauts to use the Remote Manipulator System (RMS) Canadarm as a mobile work platform; equipment with which to practice planned repairs on the Solar Maximum Mission satellite (see the 41-C mission); and a number of smaller middeck experiments and Getaway Special canisters in the cargo bay.

At 7:15:55 a.m. EST on February 11, 1984, Commander Vance Brand landed Challenger at the Kennedy Space Center, the first landing there in the Shuttle program, after a mission duration of 7 days, 23 hours, 15 minutes, and 55 seconds.

Crew. The crew members were Vance D. Brand, commander; Robert L. Gibson, pilot; and Bruce McCandless II, Ronald E. McNair, and Robert L. Steward, mission specialists.

Payload and Experiments. This mission had a large number of payload items. The Hughes-built HS-376 communications satellites for Western Union and Indonesia — Westar VI and Palapa B-2 — each had a PAM stage attached. Westar VI was deployed about eight hours after launch. Its PAM motor fired as programmed 45 minutes later, but malfunctioned and placed the satellite in an orbit much lower than the planned geosynchronous transfer. The deployment of Palapa B-2 was delayed to Flight Day 4 because of this failure. It too malfunctioned when the PAM stage fired, entering a very similar low orbit. (See STS 51-A for recovery operations.)

The 6.5-foot rendezvous targeting balloon burst while being pressurized after its release from the cargo bay. It still formed a large enough target that rendezvous operations were successfully performed. These were to test the techniques planned for the next flight, when the Solar Maximum Mission satellite would be recovered and refurbished in orbit.

On the fifth day astronauts McCandless and Stewart performed spacewalks and operated the MMU, becoming the first humans to fly in space without a safety line. The free flights were performed without difficulty, with McCandless going as far as 320 feet from the orbiter. The astronauts also tested the equipment to be used during the recovery, including a foot restraint held at the end of the RMS Canadarm. Together the two provide an astronaut the equivalent of a ride in a "cherry picker," a movable work station. During a second spacewalk on the seventh day McCandless and Stewart practiced Solar Max capture techniques, using the SPAS platform carried in the cargo bay as a substitute spacecraft. The flight plan called for SPAS to be extended on the end of the Canadarm for these practice captures, but it remained in the cargo bay throughout, due to an electrical problem with the Canadarm wrist.

Also among the experiments were five Getaway Special canisters in the cargo bay, featuring experiments in physics, biology, technology, and materials science. All were turned on as programmed by the astronauts. In the pressurized middeck area were six live rats, being studied in an experiment on arthritis; a Cinema-360 camera used by the crew throughout the mission; another in the series of Monodisperse Latex Reactor experiments; another flight of the Continuous Flow Electrophoresis System (CFES); some materials processing experiments; and other small items. The Latex Reactor and CFES equipment operated successfully, and the other experiments were performed as programmed and returned to Earth for later analysis.

On the STS 41-B mission, astronaut Bruce McCandless II tests a "cherry-picker" work platform, consisting of a mobile foot restraint held and moved by the Remote Manipulator System Canadarm. With his feet firmly anchored and his tools handy on the vertical riser, McCandless can perform useful work anywhere in the cargo bay or within 50 feet of the orbiter.

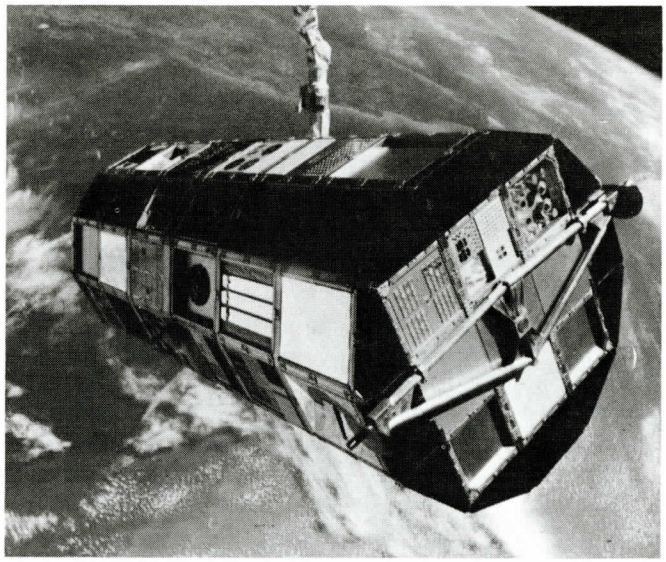
STS 41-C Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 8:58:00 a.m. EST on April 6, 1984. This was the fifth flight for Challenger and the first use of a direct ascent trajectory, where the orbiter's main engines carried it all the way to its planned operational altitude of 288 miles. This meant the Orbital Maneuvering System engines only had to be used once, to circularize the orbit.

The mission had two primary goals, the release into orbit of the reusable Long Duration Exposure Facility (LDEF), a new type of scientific satellite; and the repair in orbit of the Solar Maximum Mission satellite. The latter was the first planned repair of an orbiting spacecraft. Some of the equipment needed for this job had been carried into space and tested on the STS 41-B mission.

STS 41-C also carried a Shuttle Student Involvement Project experiment, a comb of live honeybees, in the middeck area. The Cinema-360 camera flew again in the cargo bay, and the large film IMAX camera made its first trip in the crew compartment.

To support the Solar Max rescue effort the Payload Operations Control Center (POCC) at Goddard Space Flight Center had been enlarged and upgraded. The POCC worked closely with the astronaut crew during the repair operations.



The Remote Manipulator System Canadarm suspends the huge Long Duration Exposure Facility high above the Gulf of Mexico prior to releasing it into orbit during the STS 41-C mission. This was the first set of experiments designed to be left in space for a year and then be returned to the Earth for examination and analysis.

STS 41-C was scheduled to land at the Kennedy Space Center, but bad weather in Florida forced a change to Edwards AFB. Challenger landed on Runway 17 on April 13, 1984, at 8:38:07 a.m. EST, after a mission duration of 6 days, 23 hours, 40 minutes, and 7 seconds.

Crew. The crew members were Robert L. Crippen, commander; Francis R. Scobee, pilot; and James D. van Hoften, Terry J. Hart and George D. Nelson, mission specialists.

Payload and Experiments. The LDEF is a 12-sided cylinder some 14 feet in diameter and 30 feet long. It weighs about 21,300 pounds. The body consists primarily of some 86 removable trays, into which experiments are mounted. There were 57 experiments, contributed by 200 researchers in eight countries, on this first flight; some occupied more than one tray. Each had to be self-contained and automatic in operation after being activated by the release from the orbiter. Most were passive in character, with no moving parts. One, the SEEDS experiment, required exposing some 12 million tomato seeds to the space environment for most of a year.

The LDEF was grappled by the Canadarm and released into orbit on the morning of the second day. It was to be recovered during 1985 and the seeds and other experiments returned to their owners. (See STS-32 for retrieval operations.) The scientists will determine their individual experiment results. The 12 million tomato seeds will be distributed to approximately one million school-children, who will be asked to plant them and some regular seeds, and report on the differences in growth rates and mature plants, if any.

The rendezvous with the Solar Max satellite required raising Challenger's orbit to about 300 miles altitude. On the morning of the third day, Challenger approached within about 200 feet of Solar Max and "parked" there. Astronauts Nelson and van Hoften donned spacesuits and exited into the cargo bay. Nelson got into the MMU. The capture tool, called the Trunnion Pin Acquisition Device (TPAD), was fixed to the arms of the MMU. Nelson flew out to Solar Max and attempted to clamp the TPAD on a protruding pin, but it failed to lock. After two more efforts that also failed to lock, Nelson was recalled to the orbiter.

The docking attempts had induced tumbling motions in Solar Max, and efforts to grapple it directly with the Canadarm failed because of these. But overnight the POCC at Goddard managed to reestablish control over Solar Max, using its backup system of magnetic torquing bars to stabilize the satellite and place it in a very slow, regular spin. Next morning Challenger, which had moved away before the crew's sleep period, again approached and tried the Canadarm. This time they captured Solar Max on the first try, and brought it into the cargo bay.

Solar Max was locked into a special cradle Challenger had brought for that purpose, and repairs began. Nelson and van Hoften, working in their bulky spacesuits, replaced the spacecraft's faulty Attitude Control Module and a main electronics box for the Coronograph Polarimeter instrument. This required two separate spacewalks, but the work was completed on the second one with time left for van Hoften to perform some engineering tests of the MMU in the cargo bay.

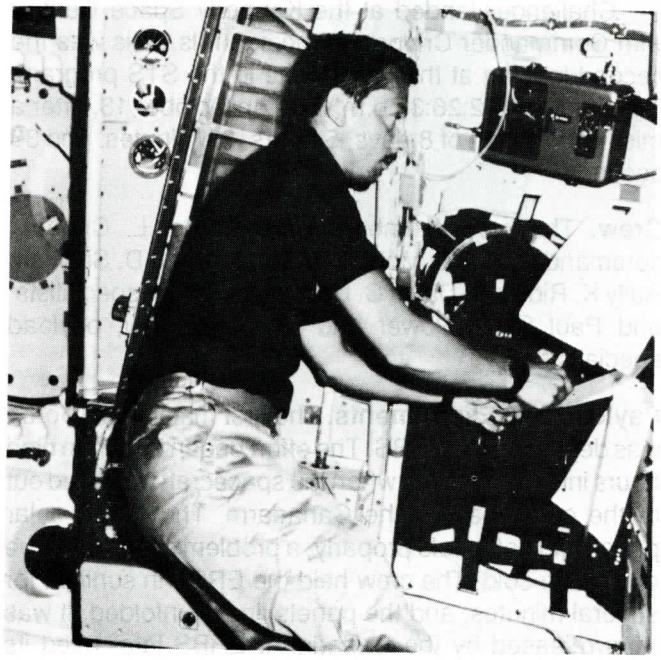
Solar Max was released into orbit the next day, checked out for 30 days by the POCC, and began measuring the Sun's total energy output. The savings resulting from repairing this scientific satellite, as opposed to building and launching a new one, amount to many millions of dollars.

The honeybees, after an initial period of disorientation in the weightlessness of space, began building a new

honeycomb as expected. The cells were crooked at first, but the bees soon corrected this and the later cells were virtually identical to those built on Earth. The Cinema-360 and IMAX cameras were operated throughout the mission, returning valuable footage. IMAX film from this and later missions was combined into movies designed for a 50 by 70 foot screen. The huge screen and large film provide extremely fine detail and outstanding clarity.

STS 41-D Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 8:41:50 a.m. EDT on August 30, 1984. The launch was delayed six minutes by an aircraft intruding into the "danger" area over the Atlantic Ocean off the coast. This was the first launch of Discovery, third spaceworthy orbiter in the STS fleet and the lightest one to date. A launch attempt on August 29 failed due to a problem with the computer software for the main engine controllers. Prior to that, Discovery had experienced the first abort-after-ignition in the Space Shuttle program, when an earlier launch attempt on June 26, 1984, was scrubbed by the onboard computers four seconds before SRB ignition. Engine No. 3 had lost redundant control over a main fuel valve immediately after ignition. Engine No. 2 had barely ignited, and Engine No. 1 had not, when the shutdown occurred.



On the STS 41-D mission Charles D. Walker, an engineer with McDonnell Douglas, became the first representative from industry to train as a payload specialist and operate his company's equipment on board the Space Shuttle.

Prior to the first launch attempt the main engines of Orbiter Discovery were test-fired on the pad for a 20-second run on June 2, 1984. The performance was nominal, leading to a planned launch date of June 22. This was later changed to June 25. The launch attempt on that date was scrubbed late in the countdown due to a failure in the backup general purpose computer. It was changed out and the substitute computer performed well during the aborted launch attempt next day.

After the launch abort the 41-D mission was remanifested to include the most important payload items from both the originally planned cargo and that intended for 41-F, which was then cancelled. (Mission 41-E had already been cancelled.) This required returning the Space Shuttle to the VAB for disassembly and then the orbiter to the OPF for cargo bay reconfiguration. The main engine which had failed was also replaced.

Once in orbit Discovery experienced no further problems and the crew successfully performed all planned work. They deployed three large communications satellites, extended and tested the OAST-1 solar cell wing, operated the CFES system, took extensive footage with the several cameras aboard, and used the Canadarm to dislodge a block of ice that appeared around a water outlet opening.

At 9:37:54 a.m. EDT on September 5, 1984, Commander Henry Hartsfield landed Discovery on Runway 17 at Edwards AFB, after a mission duration of 6 days, 0 hours, 56 minutes, and 4 seconds.

Crew. The crew members were Henry W. Hartsfield Jr., commander; Michael L. Coats, pilot; Judith A. Resnik, Steven A. Hawley and Richard M. Mullane, mission specialists; and Charles D. Walker, payload specialist. Walker, a McDonnell Douglas employee, became the first commercial payload specialist assigned by NASA to a Space Shuttle flight crew.

Payload and Experiments. The combined cargo of most major items from two prior planned missions weighed more than 47,000 pounds, the heaviest Space Shuttle payload to date. This included three communications satellites and their perigee motors. Two of these, SBS-D and Telstar 3-C, were Hughes HS-376 spacecraft with PAM-D motors attached. The third was SYNCOM IV-2, also known as LEASAT 2, a larger spacecraft built by Hughes that was specifically designed to be deployed from the Space Shuttle.

SBS-D was deployed about eight hours into the mission, SYNCOM IV-2 on the second day, and Telstar 3-C on the third day. The satellite owners/operators assumed control and responsibility once the spacecraft were clear of the orbiter. Both PAM-D motors fired

properly and carried their spacecraft into the planned geosynchronous transfer orbits. SYNCOM IV-2, which had a Minuteman Missile third stage as a solid propellant perigee motor, had a gross weight of 17,049 pounds. When fired by automatic sequence this motor boosted the spacecraft into an elliptical orbit with an apogee of about 9,500 miles. A series of firings at perigee by two small liquid hydrazine-nitrogen tetroxide engines raised the apogee to the geosynchronous altitude of 22,300 miles, and further firings circularized the orbit over the equator. The two HS-376 spacecraft used small onboard solid rocket motors, firing at apogee, to accomplish this equatorial placement and orbital circularization. The owners/operators of the three spacecraft then began checkout operations.

The SYNCOM IV-2 spacecraft, also called LEASAT 2, spins slowly away from the orbiter after being deployed during the STS 41-D mission. This was the second of three successful deployments of commercial communications satellites for 41-D, and the first using a side-spinning "frisbee" deployment system.

Smaller payloads included the OAST-1 solar wing which is 13 feet wide and extends to a height of 102 feet in space, but folds into a package only seven inches deep in its container. It featured small samples of several types of solar cells, which occupied only a fraction of the total space available. The wing was extended and refolded several times, as planned, and the orbiter's vernier engines were fired with the wing extended to determine the amount of movement and vibration under stress.

Payload Specialist Charles Walker operated the CFES in the middeck to produce a proprietary pharmaceutical product for McDonnell Douglas. Walker experienced some mechanical problems, but solved them and accomplished almost all of his planned work.

A Shuttle Student Involvement Project (SSIP) experiment on crystal growth in zero gravity was conducted. Footage using the IMAX large-film camera system was obtained throughout the mission. Other camera systems stowed in the middeck were used to photograph clouds in the atmosphere and strips of various spacecraft materials attached to the Canadarm.

STS 41-G Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 7:03:00 a.m. EDT on October 5, 1984. This was the sixth launch for the Challenger, and the thirteenth flight of the Space Shuttle. This mission included several firsts, among them the first flight with seven crew members, the first to fly two female astronauts (Ride and Sullivan), first flight by a Canadian astronaut (Garneau), first spacewalk by an American woman (Sullivan), first astronaut to fly a fourth Space Shuttle mission (Crippen), and the first demonstration of a refueling-in-orbit technique to illustrate how the useful life of some orbiting satellites can be greatly extended. One spacecraft, the Earth Radiation Budget Satellite (ERBS), was deployed on this scientifically oriented, primarily NASA mission.

Challenger landed at the Kennedy Space Center, with Commander Crippen at the controls. This was the second landing at the launch site in the STS program. The time was 12:26:33 p.m. EDT on October 13, after a mission duration of 8 days, 5 hours, 23 minutes, and 33 seconds.

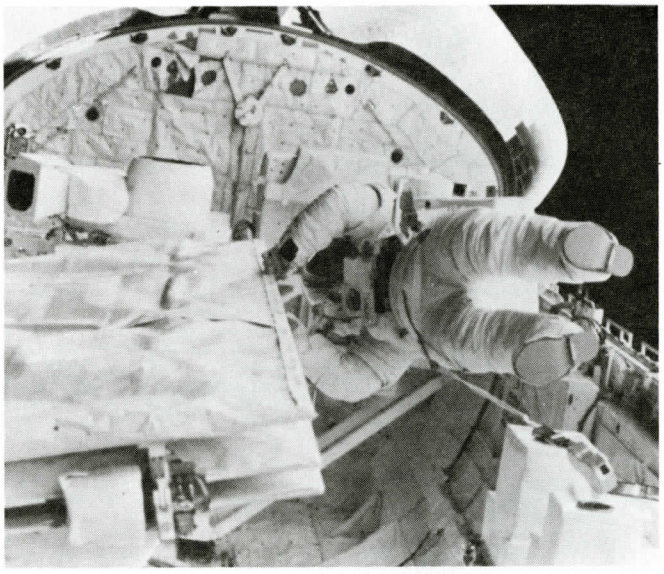
Crew. The crew members were Robert L. Crippen, commander; Jon A. McBride, pilot; Kathryn D. Sullivan, Sally K. Ride and David C. Leestma, mission specialists; and Paul Scully-Power and Marc Garneau, payload specialists.

Payload and Experiments. The first major task in orbit was deploying the ERBS. The effort began less than nine hours into the mission, when the spacecraft was lifted out of the cargo bay by the Canadarm. The ERBS solar panels did not unfold properly, a problem assumed to be due to the cold. The crew held the ERBS in sunlight for several minutes, and the panels finally unfolded. It was then released by the Canadarm. ERBS later used its onboard thrusters to raise its orbit to the operational altitude of around 350 miles.

The second major activity was the activation of the Shuttle Imaging Radar-B (SIR-B) portion of the OSTA-3

package of experiments. The radar worked well, but a failure in the ability of the orbiter's Ku-band antenna left it unable to track. The crew had to lock this antenna in place, then maneuver the entire orbiter to keep the antenna pointed at the Tracking and Data Relay Satellite (TDRS). This required storing all SIR-B data on tape, eliminating "live" transmissions, and taking far more operating time. The quality of the radar images obtained was outstanding, but the antenna problem kept data acquisition to about 20% of what had been planned. After several days and the completion of SIR-B operations, its antenna refused to fold up on command. It had to be nudged closed with the Canadarm, a delicate operation that was completed without difficulty.

The problems with the SIR-B delayed the planned spacewalks of Leestma and Sullivan by two days. Then, during three and a half hours in the cargo bay, they connected the components of the Orbital Refueling System (ORS), which was later operated several times. This demonstrated that it is possible and practical to refuel



Astronaut Kathryn D. Sullivan checks the latch of the SIR-B antenna in the Challenger's open cargo bay during her historic extravehicular activity on October 11, 1984. The primarily scientific mission of STS 41-G was to deploy an Earth Radiation Budget Satellite and perform a series of Earth observation experiments.

satellites in orbit, including some spacecraft not originally designed to have their useful lives extended.

A series of Canadian experiments (CANEX), performed in the varied fields of medical, atmospheric, climatic, materials and robotic sciences, were performed by Canadian payload specialist Garneau. The second payload specialist, Scully-Power, working for the Naval Research Laboratory, performed a series of important observations in oceanography. The astronauts also performed three more OSTA-3 experiments, taking detailed photographs of the Earth using the Large Format Camera (LFC), operating the Measurement of Air Pollution (MAPS) aerial camera, and the two television and two Hasselblad cameras in the Feature Identification and Location (FILE) experiment. The latter was also operated at times by ground command. The astronauts turned on the several experiments in the Getaway Special canisters in the cargo bay when required.

In the orbiter cabin the crew operated the IMAX large-film camera for the third time, completing the planned in-space footage for the IMAX film "The Dream is Alive." They also operated the Radiation Monitoring Equipment and performed a Thermoluminescent Dosimeter experiment to measure cosmic radiation doses during space flight. The latter was developed by the Central Research Institute for Physics in Budapest, Hungary.

The ERBS is the first of three planned sets of orbiting instruments in the Earth Radiation Budget Experiment. Two more sets will fly on NOAA weather satellites later. ERBS weighs 5,087 pounds and has three major instruments. It was built by Ball Aerospace. ERBS, when deployed, is 15 feet wide, 12.5 feet high and 5.2 feet long. The overall goal of the program is to measure the amount of energy received from the Sun and reradiated into space, and the seasonal movement of energy from the tropics to the poles.

The OSTA-3 components consisted of the SIR-B, the LFC, the MAPS, and the FILE. The SIR-A instrument on STS-2 achieved spectacular results. The improved SIR-B has an antenna consisting of a 35-by-7-foot array of eight panels. (SIR-A had seven panels.) The new antenna also tilts from 15 to 60 degrees, allowing the viewing of targets from several angles during successive orbital passes. The LFC, making its first flight, has a unique lens that combines high resolution and a wide field of view for precise stereo photography. It can resolve objects as small as 70 feet long, the length of a normal house. A single frame can photograph an area larger than the state of Massachusetts. The MAPS instrument measures the distribution of industrial wastes, such as carbon monoxide, in the troposphere over the entire globe. It consists of an aerial camera and supporting equipment. FILE is designed to help develop equipment which will make remote sensing instruments more efficient. It has two specialized television cameras, two Hasselblad 70mm cameras, and supporting equipment.

The Canadian experiment set (CANEX) consists of medical, atmospheric, materials science and robotics experiments, largely performed by Garneau, with himself as the primary medical subject.

The ORS experiment required space-suited astronauts working in the cargo bay to attach a hydrazine servicing tool, already connected to a portable fuel tank, to a simulated satellite panel. After leak checks the astronauts returned to the orbiter cabin and the actual movement of hydrazine from tank to tank was controlled from the flight deck.

The Getaway Special experiments covered a wide variety of work in materials testing and physics.

STS 51-A Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 7:15:00 a.m. EST on November 8, 1984. This was the second launch of Discovery, and the fourteenth launch of the Space Shuttle vehicle. The launch had been delayed one day by high-altitude "shear winds," a first in the Shuttle program.

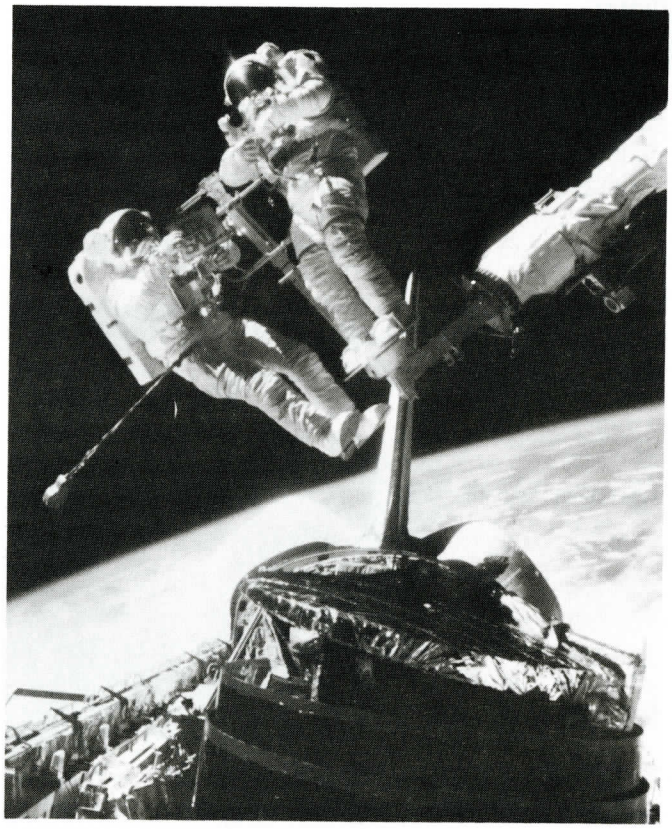
STS 51-A had two primary objectives, to deploy the Anik D-2 and SYNCOM IV-1 (LEASAT 1) communications spacecraft, and recover and return to Earth the two satellites placed in improper orbits by faulty perigee motors on STS 41-B. This recovery was the third and last segment of a three-part effort to demonstrate a new capability in the space program, the repair and/or recovery of malfunctioning satellites. The first segment was the repair in orbit of the Solar Maximum Mission satellite on STS 41-C, and the second was a demonstration of the ability to refuel satellites in orbit performed on STS 41-G.

Commander Frederick Hauck landed Discovery at the Kennedy Space Center on November 16, at 6:59:56 a.m. EST, after a mission duration of 7 days, 23 hours, 44 minutes, and 56 seconds.

Crew. The crew members were Frederick H. Hauck, commander; David M. Walker, pilot; and Joseph P. Allen, Anna L. Fisher and Dale A. Gardner, mission specialists.

Payload and Experiments. The Anik D-2 was deployed on the second day of the mission, and SYNCOM IV-1 on the third day. The orbiter then began a long series of burns needed to rendezvous with the first of the two satellites to be recovered, Palapa B-2. Both had been lowered from their original altitudes of over 600 miles to about 210 miles to facilitate recovery. Palapa B-2 was recovered on the fifth day, and Westar VI on the sixth. The usual radiation monitoring experiment was performed in the crew areas, and one major experiment, the Diffusive Mixing of Organic Solutions (DMOS), the first of over 70 organic and polymer science experiments being conducted by 3M, was successfully completed.

The Anik D-2 spacecraft, built by Spar Aerospace of Canada, with Hughes Aircraft as a major subcontractor, is very similar to the Hughes HS-376 series of communications satellites. It utilizes the PAM-D motor as a perigee stage. The SYNCOM IV-1 is a twin to SYNCOM IV-2, launched earlier on the STS 41-D mission. Each spacecraft perigee motor fired on time about 45 minutes after deployment, and both spacecraft entered the planned elliptical geosynchronous transfer orbits. A later firing of the onboard solid propellant apogee motor on Anik D-2 circularized its orbit over the equator. The Minuteman III third stage utilized by SYNCOM IV-2 as a perigee motor carried it about halfway to altitude as planned, after which



Astronaut Dale A. Gardner, left, holds a "for sale" sign to indicate he and astronaut Joseph P. Allen have just successfully captured and anchored the errant Westar VI satellite. Allen is riding the Mobile Foot Restraint held by the Canadarm, operated by astronaut Anna Fisher from inside the orbiter.

a series of firings by its hydrazine-nitrogen tetroxide thrusters raised it to the geosynchronous altitude of 22,300 miles and circularized its orbit over the equator. Both entered checkout procedures by Hughes and/or the owners in preparation for active service.

The second major mission objective was the recovery of the Palapa B-2 and Westar VI satellites. Two empty cradles similar to or identical with those from which the two satellites had originally been deployed were part of the STS 51-A cargo. After rendezvous was achieved with Palapa B-2 on the fifth day, Allen and Gardner went EVA

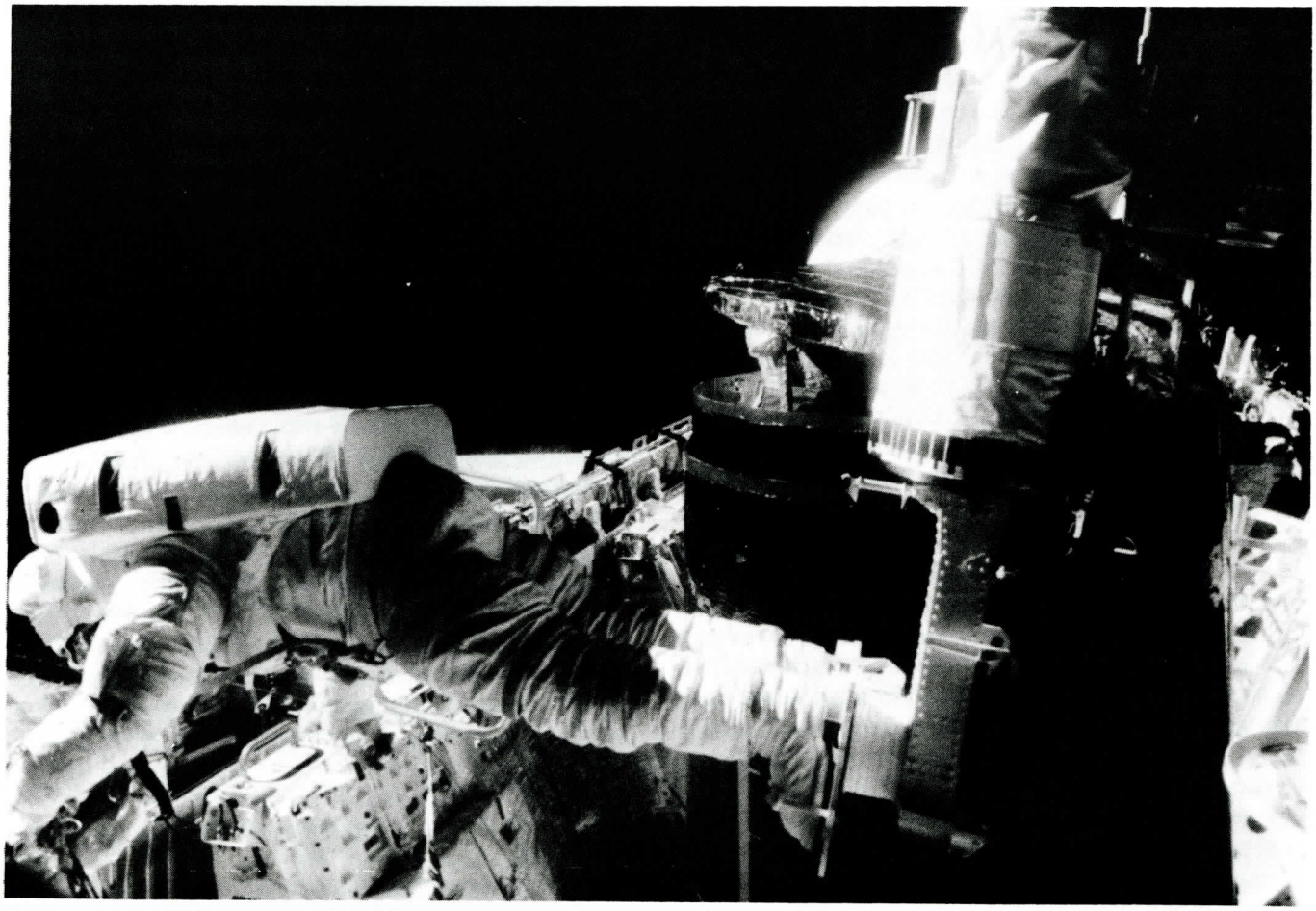
to capture the satellite. A device called a "Stinger" was inserted into the apogee motor nozzle by Allen, locking the satellite to his MMU. The MMU jets then stopped the one rpm rotation. After Allen disengaged himself and left the Stinger in place, Fisher operated the Canadarm to grasp the satellite by a special attachment on the stinger and bring it into the cargo bay. The omni antenna was removed and Gardner attempted to install a bridge structure across the top of the satellite, one with a special attach fitting that would have made it possible for Fisher to grasp it with the Canadarm. The bridge structure did not fit, making it impossible to use the Canadarm, and Allen had to manually steady the spacecraft for two hours while Gardner prepared it for berthing. It was eventually pulled down into its cradle largely by muscle power. The two astronauts, working in the microgravity of orbit, managed to move the mass of the satellite as necessary to dock and secure it in its cradle.

The Westar VI satellite was in an orbit very close to that of Palapa B-2, but about 700 miles ahead. After one more day of maneuvering Discovery caught up with it, and Allen and Gardner exchanged work assignments and captured it also. This time they did not attempt to use the bridge, but followed the same muscle-powered procedures that had worked for Palapa B-2.

The astronauts in the crew compartment operated the DMOS equipment in the middeck during the mission. The chemical mixes that resulted were turned over to 3M for analysis. The radiation monitoring which is a standard feature of STS flights was performed as usual.

1985

The Space Shuttle program scaled a pinnacle in 1985 with the completion of nine flights. By year-end, all four orbiters had flown—the newest, Atlantis, made the last flight of the year. The first missions dedicated to the Department of Defense were flown, a host of commercial satellites were deployed, and three more Spacelab flights were conducted. However, plans for continued landings at Kennedy were put on hold when the Orbiter Discovery suffered extensive brake damage and a blown tire while touching down in April. Subsequent flights were directed to land at Edwards until nose wheel steering could be implemented on the orbiters.



Astronaut Joseph P. Allen rides the Canadarm "cherry picker" attachment while suspended horizontally above the cargo bay. The spacecraft behind him is the Westar VI, which the crew had just captured and locked into the cargo bay on the STS 51-A mission.

STS 51-C Mission

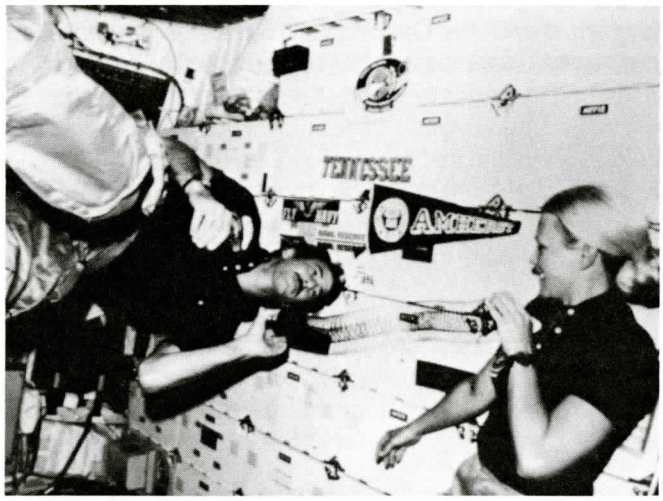
This was the first Space Shuttle mission totally dedicated to the Department of Defense. Its cargo was classified. Liftoff occurred on Jan. 24, 1985, at 2:50:00 p.m. EST, from Pad A at the Kennedy Space Center. The orbiter was Discovery. In addition to its payload the orbiter cargo bay carried an Inertial Upper Stage (IUS) booster that was deployed and successfully met its mission objectives, according to an official Air Force statement. The mission was completed in 3 days, 1 hour, 33 minutes, and 23 seconds, landing at the Kennedy Space Center. Main gear touchdown occurred at 4:23:23 p.m. EST, Jan. 27.

Crew. The crew members were Thomas K. Mattingly, commander; Loren J. Shriver, pilot; James F. Buchli and Ellison S. Onizuka, mission specialists; and Gary E. Payton of the U.S. Air Force, payload specialist.

STS 51-D Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 8:59:05 a.m. EST on April 12, 1985. This flight was a composite mission, carrying part of its original manifest and part of that from mission 51-E, which had been canceled. The crew was entirely from the canceled mission except for one of the two payload specialists, Charles Walker, who substituted for Patrick Baudry because the latter's flight experiments were no longer on the manifest. This mission also featured the first flight of an elected official, Senator E. J. "Jake" Garn (R-Utah), chairman of the Senate committee with oversight responsibilities for NASA's budget.

The Anik C-1 spacecraft was successfully deployed a few hours into the mission. Its PAM-D booster stage automatically fired 45 minutes later and lifted it into the planned elliptical geosynchronous transfer orbit. The Hughes SYNCOM IV-3 spacecraft, also called LEASAT 3, was deployed on the second day in a routine operation. However, the booster stage did not fire as programmed. The orbiter returned to the vicinity and the crew examined the spacecraft. It was determined that the 'sequence start' lever, which should have been automatically opened during the deployment sequence, was apparently not fully erected. After consultation with Hughes, Mission Control in Houston directed the astronauts in the design of two 'flyswatter' devices capable of snagging and tugging on this lever. These were attached to the end of the Remote Manipulator System (RMS, or 'Canadarm') during an EVA by Griggs and Hoffman. The mission was extended two days to permit this try at activating the satellite. Seddon manipulated the Canadarm to hook the lever and tug hard on it, but this had no affect on the spacecraft. It was eventually repaired on a later mission (see Mission 51-I, following). Discovery landed at KSC at 8:54:28 a.m. EST on April 19, after a mission duration of 6 days, 23 hours, 55 minutes, and 23 seconds. A tire blew out just before the end of the rollout, causing all following landings to be at Edwards AFB until the inactive nose wheel steering system could be activated and tested.



Mission specialists Jeffrey Hoffman (left) and Rhea Seddon demonstrate the behavior of a "slinky toy" in microgravity, one of many experiments conducted during Mission 51-D.

Crew. The crew members were Karol J. Bobko, commander; Donald E. Williams, pilot; M. Rhea Seddon, S. David Griggs, and Jeffrey A. Hoffman, mission specialists; and Charles D. Walker, McDonnell Douglas, and E. J. "Jake" Garn, United States Senate, payload specialists.

Payload and Experiments. The Anik C-1 was the third spacecraft in this series, C-2 and C-3 having been launched on previous STS missions. They are built by Hughes as part of its HS-376 series. Telesat of Canada assumed charge of its spacecraft after deployment, and later fired the onboard apogee motor to place it in geosynchronous orbit. SYNCOM IV-3 is also a Hughes spacecraft, the first specifically made to be deployed from a Space Shuttle orbiter. SYNCOM IV spacecraft are part of the Hughes HS-381 series. Each comes with its own built-in booster stage, identical to the third stage booster on the Minuteman missile, and two engines that burn monodimethyl hydrazine and nitrogen tetroxide. Both propulsion systems are required to place a SYNCOM IV in geosynchronous orbit. This series provides communications for the Department of Defense, under a contract granted to Hughes.

Other experiments included the second flight of the larger Continuous Flow Electrophoresis Experiment,

successfully operated by Walker; an informal science study of the behavior of mechanical toys in microgravity; two Shuttle Student Involvement Project (SSIP) experiments, of which one was successful and one not; a Phase Partitioning Experiment; and echocardiograph and image intensifier experiments.

STS 51-B Mission

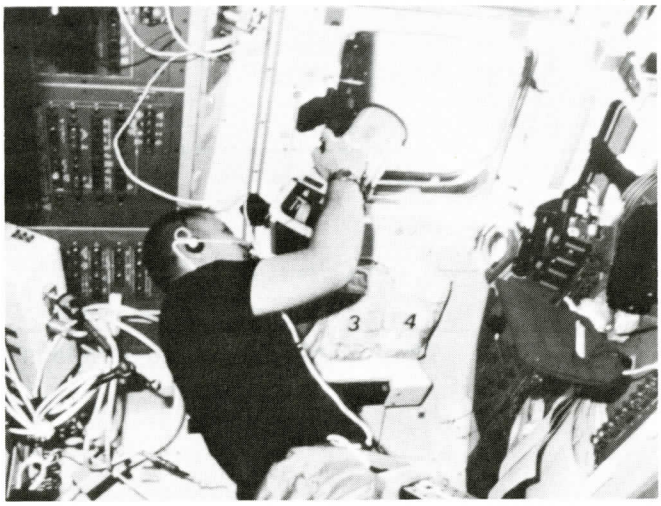
The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 12:02:18 p.m. EDT on April 29, 1985. This was the second flight of the Spacelab, the first in a fully operational configuration. Spacelab capabilities for multidisciplinary research in microgravity were successfully demonstrated. The gravity gradient attitude of the orbiter proved quite stable, allowing the delicate experiments in materials processing and fluid mechanics to proceed normally. The crew operated in two 12-hour shifts. Two monkeys and 24 rodents were flown in special cages, the first time American astronauts have flown with live mammals aboard. The astronaut experimenters in orbit were supported 24 hours a day by a temporary Payload Operations Control Center, located at the Johnson Space Center. Challenger landed at Edwards AFB at 12:11:04 p.m. EDT on May 6, 1985, after a mission duration of 7 days, 0 hours, 8 minutes, and 46 seconds.

Crew. The crew members were Robert F. Overmyer, commander; Frederick D. Gregory, pilot; Don L. Lind, Norman E. Thagard and William E. Thornton, mission specialists; and Lodewijk van den Berg, of EG&G Energy Management, Inc., and Taylor G. Wang, of Jet Propulsion Laboratory, payload specialists.

Payload and Experiments. Spacelab 3 carried a large number of experiments, including 15 primary ones, of which 14 were successfully performed. There were five basic discipline areas — materials sciences, life sciences, fluid mechanics, atmospheric physics, and astronomy — with numerous experiments in each. Two Getaway Special experiments required that they be deployed from their canisters, a 'first' in this program. These were NUSAT (Northern Utah Satellite) and GLOMR (Global Low Orbiting Message Relay Satellite). NUSAT deployed successfully, but GLOMR did not deploy and was returned to Earth.

STS 51-G Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 7:33:00 a.m. EDT on June 17, 1985. The largest items of cargo were three communications satellites. Also flown were the deployable/retrievable Spartan 1, six Getaway Special canisters, a High Precision Tracking Experiment (HPTE) for the Strategic Defense Initiative, a materials processing furnace, and French biomedical experiments.



Astronaut Robert Overmyer aims a Linhof camera at the Earth through a flight deck window on STS 51-B. The limb of the planet forms a vertical line directly above the camera.

All three communications satellites were successfully deployed and turned over to their owner-operators. Their PAM-D perigee booster motors fired and all three reached geosynchronous orbit, where they entered checkout operations. Spartan 1 was deployed and recovered. All the experiments were successfully accomplished. Discovery landed at Edwards AFB at 9:11:52 a.m. EDT on June 24, 1985, after a mission duration of 7 days, 1 hour, 38 minutes, and 52 seconds.

Crew. The crew members were Daniel C. Brandenstein, commander; John O. Creighton, pilot; Shannon W. Lucid, Steven R. Nagel, and John M. Fabian, mission specialists; and Patrick Baudry, France, and Prince Sultan Salman Al-Saud, Saudi Arabia, payload specialists.

Payload and Experiments. The three communications satellites deployed were the Arabsat 1-B (Arab Satellite Communications Organization); Morelos-1 (Mexico); and Telstar 3-D (AT&T). All three utilized PAM-D booster stages to achieve geosynchronous transfer orbits after deployment from the Discovery. The latter two spacecraft are variants of the Hughes-built HS-376 series of spin-stabilized satellites. Both use the Morton Thiokol Star 48 motor to circularize the orbit and align it with the equator at apogee. Morelos-1 provides 12 channels operating in the C-band and 6 channels operating in the Ku-band. It can provide educational and commercial television programs, telephone and facsimile services and data and business transmission services to even the most remote parts of Mexico. Telstar 3-D operates in the C-band only, and has 24 working channels. Using single

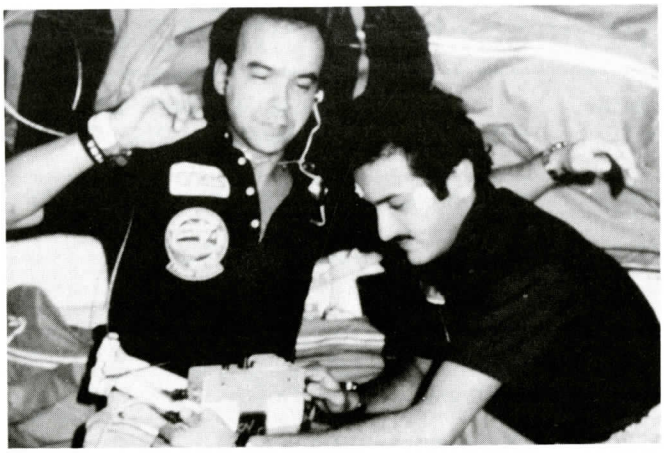
Space Shuttle Missions in Brief

FLIGHT ORDER	MISSION NAME	FLIGHT CREW	LAUNCH DATE	ORBITER	PRIMARY PAYLOAD	LAUNCH PAD	RESULT
1	STS-1	Young, Crippen	4/12/81	Columbia	- - -	39A	S
2	STS-2	Engle, Truly	11/12/81	Columbia	OSTA-1	39A	S
3	STS-3	Lousma, Fullerton	3/22/82	Columbia	OSS-1	39A	S
4	STS-4	Mattingly, Hartsfield	6/27/82	Columbia	DoD 82-1	39A	S
5	STS-5	Brand, Overmyer, Lenoir, Allen	11/11/82	Columbia	SBS-3 Anik C-3	39A	S
6	STS-6	Weitz, Bobko, Musgrave, Peterson	4/4/83	Challenger	TDRS-1	39A	S
7	STS-7	Crippen, Hauck, Ride, Fabian, Thagard	6/18/83	Challenger	Anik C-2 Palapa B-1 SPAS-1 OSTA-2	39A	S
8	STS-8	Truly, Brandenstein, Bluford, Gardner, Thornton	8/30/83	Challenger	INSAT 1B	39A	S
9	STS-9	Young, Shaw, Parker, Garriott, Merbold, Lichtenberg	11/28/83	Columbia	Spacelab 1	39A	S
10	41-B	Brand, Gibson, McCandless, McNair, Stewart	2/3/84	Challenger	Westar VI Palapa B-2 SPAS-01A	39A	P
11	41-C	Crippen, Scobee, van Hoften, Nelson, Hart	4/6/84	Challenger	LDEF	39A	S
12	41-D	Hartsfield, Coats, Hawley, Resnik, Mullane, Walker	8/30/84	Discovery	SBS-4 Telstar 3-C SYNCOM IV-2	39A	S
13	41-G	Crippen, McBride, Sullivan, Ride, Leestma, Garneau, Scully-Power	10/5/84	Challenger	ERBS OSTA-3	39A	S
14	51-A	Hauck, Walker, Allen, Fisher, Gardner	11/8/84	Discovery	Anik D-2 SYNCOM IV-1 Palapa B-2 (retrieval) Westar VI (retrieval)	39A	S
15	51-C	Mattingly, Shriver, Buchli, Onizuka, Payton	1/24/85	Discovery	DoD	39A	S
16	51-D	Bobko, Williams, Seddon, Griggs, Hoffman, Garn, Walker	4/12/85	Discovery	Anik C-1 SYNCOM IV-3	39A	P
17	51-B	Overmyer, Gregory, Lind, Thagard, Thornton, van den Berg, Wang	4/29/85	Challenger	Spacelab 3	39A	S
18	51-G	Brandenstein, Creighton, Lucid, Nagel, Fabian, Baudry, Al-Saud	6/17/85	Discovery	Arabsat 1-B Telstar 3-D Morelos-A	39A	S

S = Successful P = Partially Successful U = Unsuccessful

FLIGHT ORDER	MISSION NAME	FLIGHT CREW	LAUNCH DATE	ORBITER	PRIMARY PAYLOAD	LAUNCH PAD	RESULT
19	51-F	Fullerton, Bridges, Musgrave, England, Henize, Acton, Bartoe	7/29/85	Challenger	Spacelab 2	39A	S
20	51-I	Engle, Covey, van Hoften, Lounge, Fisher	8/27/85	Discovery	AUSSAT 1 ASC 1 SYNCOM IV-4	39A	S
21	51-J	Bobko, Grabe, Stewart, Hilmers, Pailes	10/3/85	Atlantis	DoD	39A	*
22	61-A	Hartsfield, Nagel, Buchli, Bluford, Dunbar, Furrer, Ockels, Messerschmid	10/30/85	Challenger	Spacelab D-1	39A	S
23	61-B	Shaw, O'Connor, Cleave, Spring, Ross, Vela, Walker	11/26/85	Atlantis	Morelos-B AUSSAT-2 RCA Satcom Ku-2	39A	S
24	61-C	Gibson, Bolden, Chang-Diaz, Hawley, Nelson, Cenker, Nelson	1/12/86	Columbia	RCA Satcom Ku-1	39A	S
25	51-L	Scobee, Smith, McNair, Resnik, Onizuka, Jarvis, McAuliffe	1/28/86	Challenger	TDRS-B	39B	U
26	STS-26	Hauck, Covey, Lounge, Nelson, Hilmers	9/29/88	Discovery	TDRS-3	39B	S
27	STS-27	Gibson, Gardner, Ross, Mullane, Shepherd	12/2/88	Atlantis	DoD	39B	*
28	STS-29	Coats, Blaha, Buchli, Springer, Bagian	3/13/89	Discovery	TDRS-4	39B	S
29	STS-30	Walker, Grabe, Cleave, Lee, Thagard	5/4/89	Atlantis	Magellan	39B	S
30	STS-28	Shaw, Richards, Brown, Adamson, Leestma	8/8/89	Columbia	DoD	39B	*
31	STS-34	Williams, McCulley, Baker, Chang-Diaz, Lucid	10/18/89	Atlantis	Galileo	39B	S
32	STS-33	Gregory, Blaha, Musgrave, Carter, Thornton	11/22/89	Discovery	DoD	39B	*
33	STS-32	Brandenstein, Wetherbee, Dunbar, Ivins, Low	1/9/90	Columbia	SYNCOM IV-5 LDEF Retrieval	39A	S
34	STS-36	Creighton, Casper, Hilmers, Mullane, Thuot	2/28/90	Atlantis	DoD	39A	*
35	STS-31	Shriver, Bolden, Hawley, McCandless, Sullivan	4/24/90	Discovery	Hubble	39B	S
36	STS-41	Richards, Cabana, Shepherd, Melnick, Akers	10/6/90	Discovery	Ulysses	39B	S
37	STS-38	Covey, Culbertson, Meade, Springer, Gemar	11/15/90	Atlantis	DoD	39A	*
38	STS-35	Brand, Gardner, Lounge, Hoffman, Parker, Parise, Durrance	12/2/90	Columbia	Astro-1	39B	S

* The Department of Defense (DoD) does not discuss payloads flown on classified missions.



Payload specialists Patrick Baudry of France (left) and Salman Al-Saud of Saudi Arabia conduct a French postural experiment in the middeck of Discovery on STS 51-G.

sideband technology, a Telstar can relay up to 86,400 two-way telephone calls. Both spacecraft are about 22 feet high and 7 feet wide when deployed, and have a mass of around 1,450 pounds when operational.

Arabsat 1 satellites are built by an international team led by Aerospatiale of France. It is a three-axis stabilized spacecraft with two deployable solar array wings, making it almost 68 feet long and over 18 feet wide when deployed in orbit. It weighs about 2,800 pounds in its initial orbit, but some 1,490 pounds of this is propellant. It has an onboard low-thrust motor that utilizes hydrazine and nitrogen tetroxide, and transfers from an initial elliptical to geosynchronous orbit by firing this motor. The remaining propellant is then used for station-keeping or moving, over the life of the satellite.

Spartan 1, a payload carrier with the capability of independent flight, maneuvers in space alongside Discover during STS 51-G.

Spartan 1 measured 126 by 42 by 48 inches, and weighed 2,223 pounds. The Spartan is a carrier, designed to be deployed from the orbiter and fly free in space before being retrieved. Spartan 1 included 300 pounds of experiments in the field of astronomy. It was deployed and operated successfully, independent of the orbiter, before being retrieved.

The materials furnace, French biomedical experiments, and six Getaway Special experiments were all successfully performed, although the GO34 Getaway Special shut down prematurely. The Strategic Defense Initiative experiment failed during its first try on orbit 37 because the orbiter was not at the correct attitude. It was successfully completed on orbit 64.

STS 51-F Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 5:00:00 p.m. EDT on July 29, 1985. The largest item of cargo aboard was Spacelab 2, the second and last Spacelab verification mission. Verification Flight Instrumentation (VFI) was strategically located throughout Spacelab 2 and at the Spacelab interfaces with the Orbiter Challenger. Spacelab 3, flown out of sequence ahead of Spacelab 2, was an operational mission, using essentially the same operating equipment already verified on Spacelab 1.

This mission was originally scheduled for launch on July 12, 1985. Main engine ignition was achieved on that date, but a malfunction in a coolant valve on the No. 2 engine resulted in the computer shutting down all three engines at T-3 seconds.

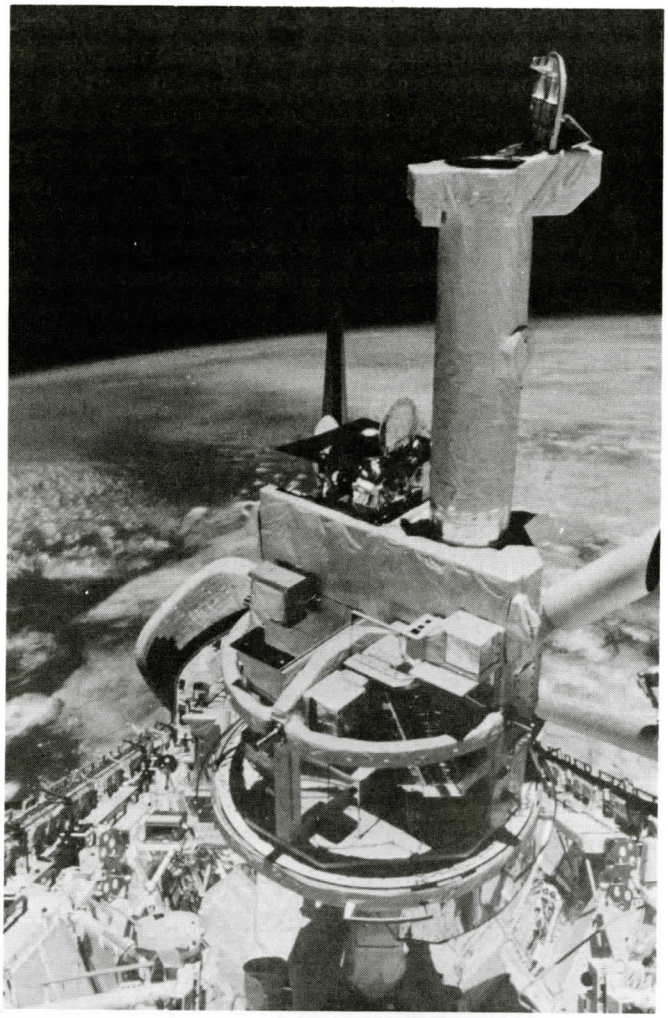
Liftoff on July 29 was delayed by approximately 1 hour and 37 minutes due to an orbiter problem. The flight then proceeded normally until the No. 1 engine shut down prematurely at 5 minutes and 45 seconds after liftoff. This resulted in an abort-to-orbit trajectory and an initial orbital altitude of 124 by 165 miles. This was later corrected by OMS burns to reach an altitude of 196 by 197 miles.

Once in orbit the mission went well, with good results being obtained by all major experiment instruments. The mission was extended to eight days from the planned seven, to obtain more data. Challenger landed at Edwards AFB at 3:45:26 p.m. EDT on August 6, 1985, after a mission duration of 7 days, 22 hours, 45 minutes, and 26 seconds.

Crew. The crew members were Charles G. Fullerton, commander; Roy D. Bridges, pilot; F. Story Musgrave, Anthony W. England and Karl G. Henize, mission specialists; and Loren W. Acton, Lockheed Corporation, and John-David Bartoe, Naval Research Laboratory, payload specialists.

Payload and Experiments. The VFI system operated normally during launch and ascent, obtaining good data

which was relayed to the ground later via the TDRS. The VFI instruments continued to operate normally throughout the mission. All of the 13 planned detailed test objectives were accomplished.



During STS 51-F, the Instrument Pointing System uses star locations for stable reference points and then furnishes guidance to the sensitive astronomical instruments aboard Spacelab 2.

This was the first Spacelab mission where most instruments were mounted on a three-pallet train and open to space. A separate container protected one large experiment, on the elemental composition and energy spectra of cosmic ray nuclei, located behind the pallet train at the rear of the cargo bay. To provide the fine pointing accuracy needed by the solar and astronomy experiments on pallet 1, an Instrument Pointing System (IPS), developed by the European Space Agency, was flown on this mission. The IPS features a three-axis gimbal system that can orient instruments of up to 4,400 pounds mass within an accuracy of 1-arc second. During Verification Flight Testing of the IPS some problems occurred in acquiring and fine tracking of the Sun, using the optical sensor package. Onboard troubleshooting enabled the development on the ground of a series of software patches that corrected the problem.

Four experiments were conducted inside the pressurized crew compartment. Two dealt with Vitamin D metabolites and bone demineralization, which included taking physiological measurements of the flight crew members. A third was to determine the effect of weightlessness upon lignification in plants. The fourth, added late in mission planning, dealt with protein crystal growth. All were highly successful.

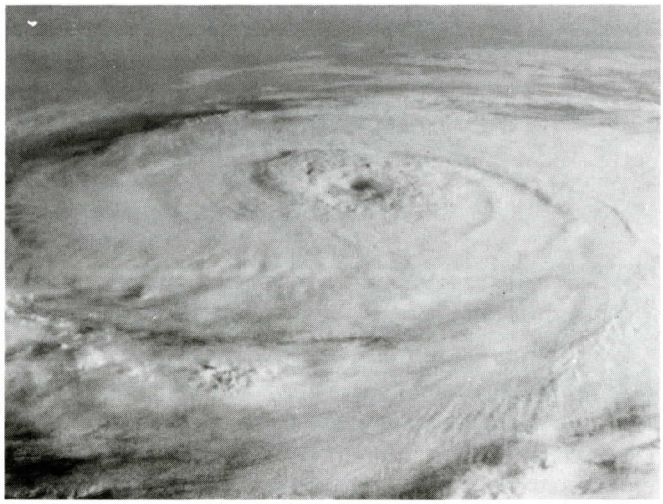
The pallet-mounted instruments conducted experiments or gathered data in the areas of plasma physics, infrared astronomy, high-energy physics, solar physics, atmospheric physics, and technology. The instruments were operated by the crew from inside the pressurized compartment, or by ground control. A special part of the modular Spacelab system located at the head of the train, called the Igloo, provided on-site support services to the instruments mounted on the pallets. These support subsystems are designed to operate in a pressurized environment, and the Igloo is the only part of this configuration of the Spacelab that requires pressurization. The equipment in the Igloo can vary. For this mission it included three computers, one mass memory, a power controller, subsystem power distribution, multiplexer, a freon cooling loop, and other support components.

The highly trained Spacelab 2 crew carried out experiments for which there were few precedents except rehearsals. The crew held frequent conversations with experts on the ground. As a result, the data and images acquired appear to be of very high quality.

STS 51-I Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 6:58:01 a.m. EDT on August 27, 1985. The cargo consisted of three communications satellites and one middeck experiment. The launch was originally planned for August 24, but was delayed due to thunderstorms and lightning in the pad areas. It was further delayed until August 27 to replace a failed general purpose computer (No. 5) and to inspect the main engine ducts. This mission had the unusual responsibility of capturing and repairing a spacecraft, SYNCOM IV-3 (deployed on the earlier Discovery mission 51-D the previous April), after first deploying SYNCOM IV-4.

The remaining two spacecraft were AUSSAT-1 and American Satellite Company 1 (ASC-1). The AUSSAT sunshield hung up on the satellite's omni antenna when an attempt was made to reopen the sunshield to perform a spacecraft health check. The Canadarm was then used to open the deformed sunshield. To avoid more heat from



The flight deck of Discovery offers an oblique view of Hurricane Elena, taken September 2, 1985, during STS 51-I. The structure of almost the entire storm can be seen in this single photograph.

sunlight than was allowable on the spacecraft and attached booster stage, AUSSAT-1 was deployed a day early, on August 27. ASC-1 was deployed the same day.

SYNCOM IV-4 was deployed on August 29. A scheduled backup day was not needed, enabling SYNCOM IV-3 rendezvous maneuvers to begin a day earlier than planned. Fisher and van Hoften performed an EVA to capture the satellite on Flight Day 5. Power had been lost on the Canadarm elbow joint, when operating in the primary mode, on the first day. This limitation caused operations to go slowly. A second EVA was required the next day. The installation of a bypass system to provide ground control of the spacecraft was successfully completed. At a later date, the satellite was placed in the correct orbit and entered normal service.

Orbiter Discovery landed at Edwards AFB on September 3, 1985, at 9:15:43 a.m. EDT, after a mission duration of 7 days, 2 hours, 17 minutes, and 42 seconds.

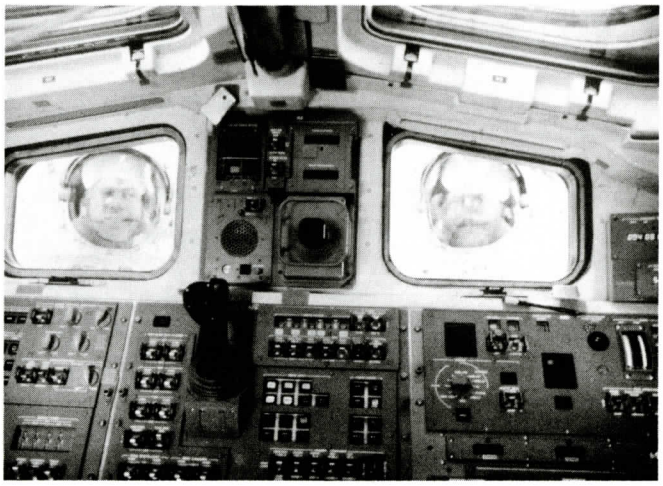
Crew. The crew members were Joe H. Engle, commander; Richard O. Covey, pilot; and James van Hoften, John M. Lounge and William F. Fisher, mission specialists.

Payload and Experiments. Two of the three communications spacecraft, AUSSAT-1 and ASC-1, were equipped with a PAM-D booster stage. The third, SYNCOM IV-4, utilizes a Minuteman third stage as a booster. (See mission 51-D for a more complete description of a SYNCOM IV.)

The AUSSAT system is designed to provide a wide range of domestic communications services to the entire continent of Australia and its offshore islands. This includes direct television broadcasts to isolated homesteads and remote communities, high quality television relays between major cities, digital data transmission for business use, centralized air traffic control services, and maritime and land-based radio coverage. AUSSAT-1 is a Hughes HS-376 model, and operates 15 channels in the 14/12 GHz Ku-band.

The ASC-1 satellite provides voice, data, facsimile, and videoconferencing communications services to U.S. businesses and government agencies. It is a hybrid spacecraft, providing channels in both the 6/4 and 14/12 GHz bands. A unique 'first' for the ASC series is their encrypted command links, a security feature which guards against unauthorized access to the satellite command system. ASC spacecraft are built by RCA Astro Electronics.

The payload item in the pressurized crew compartment was the second in a series by the 3M Company, dealing with the Physical Vapor Transport of Organic Solids (PVTOS). The experiment was conducted successfully.



During a light moment on STS 51-I, Mission specialists William Fisher (left) and James van Hoften peer into the crew compartment of Discovery through the front windows. They were performing an EVA to capture the SYNCOM IV-3 satellite.

STS 51-J Mission

This was the second Space Shuttle mission totally dedicated to the Department of Defense. Its cargo was classified. Liftoff occurred on October 3, 1985, at 11:15:30 a.m. EDT, from Pad A, Launch Complex 39, Kennedy Space Center. The orbiter was Atlantis, making its first flight. The mission was classified as "successful." After a duration of 4 days, 1 hour, 44 minutes, and 38 seconds, Atlantis landed on Runway 23 at Edwards AFB at 1:00:08 p.m. EDT on October 7, 1985.

Crew. The crew members were Karol J. Bobko, commander; Ronald J. Grabe, pilot; David C. Hilmers and Robert L. Stewart, mission specialists; and William Pailes, U.S. Air Force, payload specialist.

STS 61-A Mission

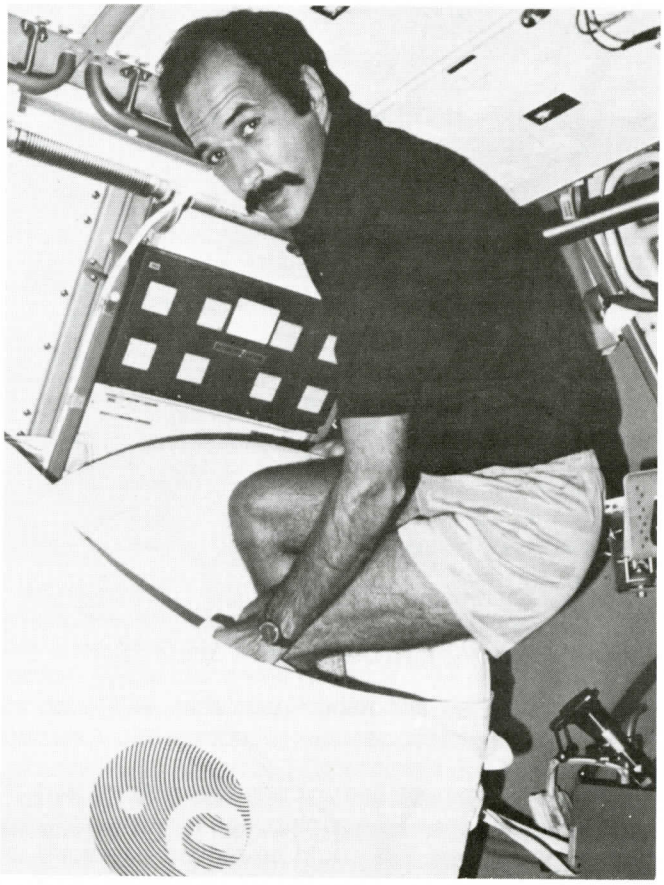
The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 12:00:00 noon EST on October 30, 1985. This was the first Space Shuttle mission largely financed and operated by another nation, West Germany. It was also the first Space Shuttle flight to carry a crew of eight. The primary mission was to operate a series of experiments, almost all related to functions in microgravity, in Spacelab D-1, the fourth flight of Spacelab. Two other mission assignments were to deploy the Global Low Orbiting Message Relay Satellite (GLOMR) out of a Getaway Special canister in the cargo bay, and operate five materials processing experiments mounted in the cargo bay on a separate device called the German Unique Support Structure.

NASA operated the Space Shuttle, and was responsible for overall safety and control functions throughout the flight. West Germany was responsible for the scientific research carried out during the seven-day mission. To fulfill this function German scientific controllers on the ground worked closely with the personnel in orbit, operating out of the German Space Operations Center at Oberpfaffenhofen, near Munich, West Germany. The orbiting crew divided into two teams, and operated 24 hours a day. Communications were very good throughout the mission and the ground and orbital crews were able to interact regularly. The overall system of one Center controlling spacecraft operations and a second controlling experiment functions worked very smoothly in practice.

The GLOMR satellite was successfully deployed during the mission. The five experiments mounted on the separate structure behind the Spacelab module obtained good data. Orbiter Challenger landed on Runway 17 at Edwards AFB on November 6, 1985. Main gear touchdown occurred at 12:44:51 p.m. EST, after a mission duration of 7 days, 0 hours, 44 minutes, and 51 seconds.

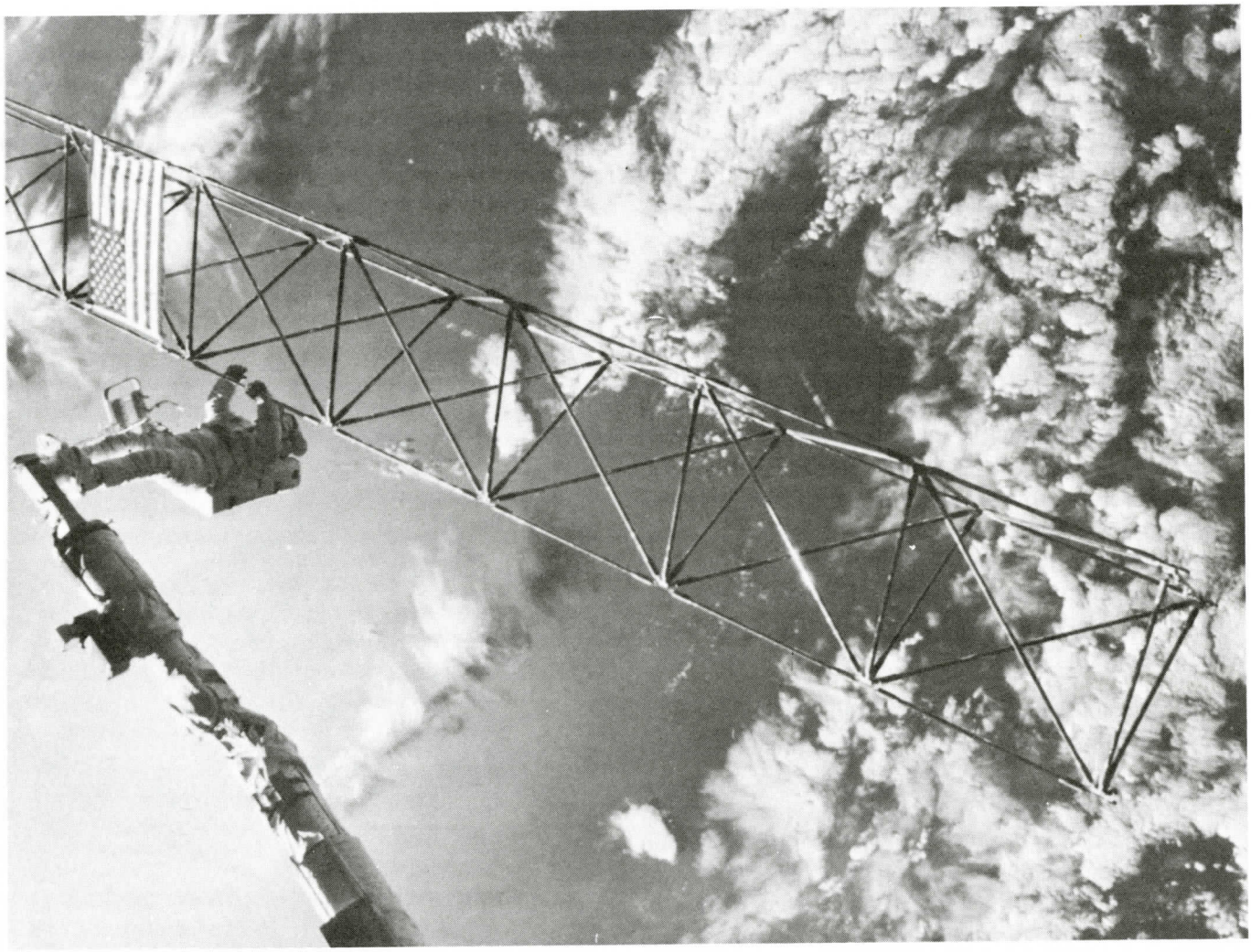
Crew. The crew members were Henry W. Hartsfield Jr., commander; Steven R. Nagel, pilot; Bonnie J. Dunbar, James F. Buchli and Guion S. Bluford Jr., mission specialists; and Ernst Messerschmid and Reinhard Furrer, Germany, along with Wubbo Ockels, European Space Agency, payload specialists.

Payload and Experiments. The science research effort on Spacelab D-1 encompassed some 75 numbered experiments, most of which were performed more than once. Some of these experiments had predecessors which had returned data obtained on earlier flights. This made it possible to prepare experiment regiments that were 'second generation' with respect to technical concept and experiment installation. Almost all of them took advantage of the microgravity environment to perform work not possible, or very much more difficult to do, on Earth. The major area of concentration was materials science, in which Germany has a well developed expertise.



During Mission 61-A, payload specialist Wubbo Ockels lifts himself out of a special sleeping bag designed by a Dutch company. The device allowed the European Space Agency representative to become the first person to sleep in the Spacelab instead of the orbiter.

The primary areas of experiment concentration were: fluid physics, with experiments in capillarity, Marangoni convection, diffusion phenomena, and critical point; solidification experiments; single crystal growth; composites; biological, including cell functions, developmental processes, and the ability of plants to perceive gravity; medical, including the gravitational perceptions of hu-



Astronaut Sherwood Spring, working from a platform on the end of the Remote Manipulator System Canadarm during Mission 61-B, helps erect the EASE-ACCESS experiment on the deployment of large structures in space. Such experiments are vital to planners preparing for assembly of the Space Station in the mid-1990s.

mans, and their adaptation processes in space; and speed-time interaction studies of people working in space.

One equipment item of unusual interest was the Vestibular Sled, an ESA contribution consisting of a seat for a test subject that could be moved backward and forward with precisely controlled accelerations and stops, along rails fixed to the floor of the Spacelab aisle. By taking detailed measurements on a human strapped into the seat, scientists gained data on the functional organization of the human vestibular and orientation systems, and the vestibular adaptation process under microgravity. The acceleration experiments by the sled riders were combined with thermal stimulations of the inner ear and optokinetic stimulations of the eye.

Overall, this was the most comprehensive series of experiments to date on materials processing in space and associated human activities, adding a rich store to humanity's knowledge. The data that was gained will require years of analysis.

STS 61-B Mission

The Orbiter Atlantis lifted off from Pad A, Launch Complex 39, KSC, at 7:29:00 p.m. EST on November 26, 1985, the second night launch in the Shuttle program and the second flight for Atlantis. The primary payload of three communications satellites were successfully deployed, one at a time, and a major demonstration of construction techniques to build structures in orbit was successfully accomplished. This activity was filmed by an IMAX large-film camera mounted in the cargo bay, obtaining some excellent coverage. Three experiments located in the pressurized crew compartment were also completed, with good data obtained. The landing was at Edwards AFB, at 4:33:49 p.m. EST on December 3, 1985, after a mission duration of 6 days, 21 hours, 4 minutes, and 49 seconds.

Crew. The crew members were Brewster H. Shaw Jr., commander; Bryan D. O'Connor, pilot; Mary L. Cleave, Sherwood C. Spring and Jerry L. Ross, mission specialists; and Rodolfo Neri Vela, Mexico, and Charles Walker, McDonnell Douglas, payload specialists.

Payload and Experiments. Two of the three communications satellites were AUSSAT-2 and Morelos-B, in each case the second in its series. (See mission 51-I and 51-G.) Both were Hughes HS-376 satellites equipped with a PAM-D booster to reach geosynchronous transfer orbit. The third spacecraft was the SATCOM Ku-2, a version of the RCA 4000 series. RCA American Communications owns and operates the satellite system of which SATCOM Ku-2 is a part. It was attached to a PAM-D2 booster, a larger version of the PAM-D. This was the first flight of this booster stage on a Space Shuttle.

All three spacecraft were successfully deployed, one at a time, and their booster stages fired automatically to lift them to geosynchronous transfer orbits. Their respective owners assumed charge, and later fired the onboard kick-motors at apogee, to circularize the orbits and align them with the equator.

SATCOM Ku-2 has 16 channels and operates entirely in the Ku (14/12 GHz) range. Each channel has an output power of 45 watts and a bandwidth of 54 MHz, enough to make reception practical on a home antenna as small as three feet in diameter. This was the first of three spacecraft planned to form a complete operating system. Future planned service areas are homes that cannot receive cable television services, multi-unit residential complexes such as condominiums and apartment houses, hotels, hospitals, and schools; and a syndication system to deliver time-sensitive programming to commercial broadcast television stations.

An item of major interest was EASE/ACCESS, an experiment in assembling large structures in space. ACCESS was a 'high-rise' tower composed of many small struts and nodes. EASE was a geometric structure shaped like an inverted pyramid, composed of a few large beams and nodes. Together they demonstrated the feasibility of assembling large pre-formed structures in space. The IMAX camera mounted in the cargo bay filmed the activities of the astronauts engaged in the EASE/ACCESS work, as well as other scenes of interest.

Rudolfo Neri Vela accomplished a series of experiments, primarily in human physiology. Charles Walker again operated the Continuous Flow Electrophoresis System, the third flight of this larger and improved equipment to produce commercial pharmaceutical products in microgravity. An experiment in Diffusive Mixing of Organic Solutions, or DMOS, was operated successfully for the 3M Company. The object is to grow single crystals in microgravity that are larger and more pure than any that can be grown on Earth. One Getaway Special canister in the cargo bay carried an experiment by Canadian students to fabricate mirrors in microgravity with higher performance than ones made on Earth.

All the experiments on this mission were successfully accomplished, and all equipment operated within established parameters.

1986

Plans to resume Shuttle landings at KSC were thwarted by bad weather, prompting the first Shuttle flight of 1986 to conclude with a landing at Edwards Air Force Base, Calif. The second launch, Mission 51-L, ended in disaster when crew and vehicle were lost 73 seconds after liftoff due to a failed seal in a solid rocket booster. 51-L was the first liftoff from Pad 39B; Pad 39A was used exclusively for the first 24 Shuttle flights. After the accident, the Space Shuttle program was grounded for two and a half years while the cause of the mishap was investigated and a program of recovery and return to flight implemented. Plans to begin Space Shuttle launches from Vandenberg Air Force Base in 1986 were abandoned, as were plans to fly the Centaur upper stage on the Shuttle.

STS 61-C Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 6:55:00 a.m. EST on January 12, 1986. This launch had been postponed several times from an originally planned date of December 18. On that date it was delayed to December 19 because of excess time needed to close out the aft compartment. On December 19 the count was halted at T-14 seconds due to an out-of-tolerance reading on the right solid rocket booster hydraulic system. Another launch attempt on January 6 was halted at T-31 seconds due to a problem with the fill and drain valve in the liquid oxygen system; the window ended before the problem could be resolved. On January 7 the launch team tried again, but marginal weather for an emergency return to KSC plus bad weather at the emergency landing sites in Dakar and Moron forced a postponement. The January 9 planned launch was delayed an extra day to permit removal of an obstruction in the Space Shuttle main engine No. 2 liquid oxygen prevalve. On January 10 another launch attempt was made, but eventually called off due to heavy rains in the pad area. The actual liftoff on January 12 was then achieved without major incident.

The primary payload of the RCA Ku-1 satellite was successfully deployed. Most of the large number of small payloads and experiments in the cargo bay and crew compartment were successfully operated. One excep-

tion was the Comet Halley Active Monitoring Program (CHAMP), which did not function properly due to battery problems.

Mission controllers decided to shorten the planned flight by one day to provide more processing time on the ground for the next flight of Columbia, in an effort to bring it in at KSC on January 16. The landing attempt had to be waved off on that day due to unfavorable weather at KSC, and was waved off again the next day as well. The mission was extended one more day for another KSC attempt, but when it also had to be waved off because of weather, Columbia landed at Edwards AFB instead. Main gear touchdown occurred at 8:58:51 a.m. EST on January 18, after a mission duration of 6 days, 2 hours, 3 minutes, and 51 seconds.

Crew. The crew members were Robert L. Gibson, commander; Charles F. Bolden Jr., pilot; Franklin Chang-Diaz, Steven A. Hawley, and George D. Nelson, mission specialists; and Robert Cenker, RCA Astro-Electronics, and Bill Nelson, United States House of Representatives, payload specialists.

Payload and Experiments. This mission carried an unusually large number of small experiments. The one large item was the SATCOM Ku-1, the second in this series of communications satellites for RCA Americom (see Mission 61-B for a description of the spacecraft and its attached PAM-D2 booster stage). There were 13 Getaway Special canisters, 12 mounted on a GAS Bridge Assembly that reaches from side to side across the cargo bay, and one attached to the GAS canister mounts on the right wall nearby. These provided a wide variety of experiments, including ones in microgravity dealing with materials processing, seed germination, egg hatching, and chemical reactions; astronomy observations; and atmospheric physics experiments.

A second experiment carrier that reaches across the cargo bay was flown for the first time, the Materials Science Laboratory-2 structure. It carried three larger experiments exploring liquid bubble suspension by sound waves, melting and resolidification of metallic samples, and containerless melting and solidification of electrically conductive specimens.

A third small payloads carrier called the Hitchhiker G-1 (HHG-1) attached to two GAS canister mounts on the cargo bay right wall near the front. It carried three experiments, to film particles in the local environment, test a new heat transfer system, and determine the effects of contamination and atomic oxygen on ultraviolet optics materials.

Three experiments in the pressurized crew compartment were by students working in the Shuttle Student Involvement Program, and dealt with the measurement of auxin levels and starch grains in plant roots, air injection as an alternative to honeycombing in metals, and a study of paper fiber formation in microgravity. Another cabin experiment measured the sedimentation level of whole blood stored in microgravity.

The CHAMP experiment consisted primarily of a 35mm camera to photograph Comet Halley through the aft flight deck overhead window. This experiment was not successful.

STS 51-L Mission

The Orbiter Challenger lifted off from Pad B, Launch Complex 39, KSC, at 11:38:00 a.m. EST on January 28, 1986. At just under 74 seconds into the flight a leaking right solid rocket booster caused the loss of vehicle and crew.

Crew. The crew members were Francis R. Scobee, commander; Michael J. Smith, pilot; Judith A. Resnik, Ellison Onizuka, and Ronald E. McNair, mission specialists; and S. Christa McAuliffe, New Hampshire schoolteacher, and Gregory B. Jarvis, Hughes Aircraft, payload specialists.

Payload and Experiments. The primary item of cargo was the second Tracking and Data Relay Satellite (TDRS), with an attached Inertial Upper Stage (IUS) booster for the planned transfer to geosynchronous orbit. Also aboard was the Spartan, a free-flying module designed to operate independently of the orbiter and observe Halley's Comet with two ultraviolet spectrometers and two cameras. Several small experiments were carried in the pressurized crew compartment, including a set of lessons planned for live television transmission by S. Christa McAuliffe, a teacher and the first passenger-observer in the U.S. manned space program.

1988

The NASA and contractor team worked hard during the approximately 32-month launch hiatus to get America back into manned space flight. Hundreds of changes—many planned before the accident and others because of it—were implemented on flight hardware and ground support systems. The Orbiter Discovery, selected to fly first when launches resumed, began preflight processing in 1987. Rollout to Pad 39B was celebrated in July 1988, followed by more grueling preflight tests. The return-to-flight effort began with STS-26 in September 1988 and was declared complete in August the following year, when all three remaining orbiters had flown at least one mission. Pad B was used exclusively for Shuttle liftoffs until January 1990 while Pad A underwent extensive modifications. NASA was directed to concentrate on

launching scientific spacecraft from the Shuttle, while all commercial and most military payloads were sent up on a revived fleet of unmanned launch vehicles.

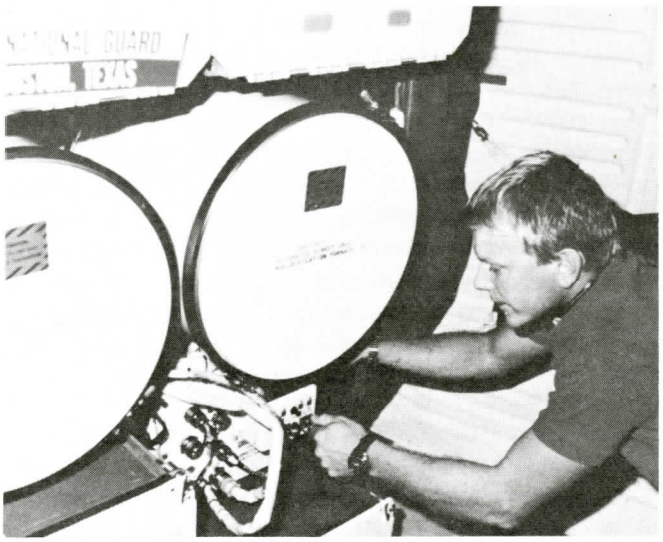
STS-26 Mission

The Space Shuttle Discovery (OV-103) lifted off from Pad B, Launch Complex 39, Kennedy Space Center, at 11:37:00 a.m. EDT on Sept. 29, 1988. Launch of America's return-to-flight mission was delayed for 1 hour and 38 minutes because of unseasonable and unusual light winds aloft, and to replace fuses in the cooling systems of two crew members' flight suits. The suits were repaired, and a waiver was issued for the wind conditions after officials determined there was a sufficient safety margin for wind loads on the orbiter wing leading edges. The 26th Shuttle flight was the seventh for Discovery.

The primary payload for the STS-26 mission, a Tracking and Data Relay Satellite (TDRS), was successfully deployed, and 11 scheduled middeck scientific and technological experiments were carried out. The orbiter sustained only minor Thermal Protection System tile damage and the redesigned solid rocket boosters showed no signs of leakage or overheating at any of the joints.

Two minor problems occurred during the flight. After ascent, the Flash Evaporator System for cooling the orbiter iced up and shut down, increasing the crew cabin temperature to approximately 87 degrees Fahrenheit. The problem was resolved on Flight Day 4 and cooler temperatures resulted. A Ku-band antenna for communications was successfully deployed on Flight Day 2, but it failed to respond properly and had to be stowed for the remainder of the mission.

STS-26 crew members show that right side up and upside down are relative terms in the microgravity environment aboard the Space Shuttle. Clockwise from the top in the middeck area are commander Frederick H. "Rick" Hauck, mission specialists John M. "Mike" Lounge and George D. "Pinky" Nelson, pilot Richard O. Covey and mission specialist David C. Hilmers.



STS-26 Mission specialist George D. "Pinky" Nelson operates the controls of the Automatic Directional Solidification Furnace, which had some equipment problems during the four-day mission.

Besides conducting the various experiments, crew members practiced suiting up in new partial-pressure, or launch-and-entry, flight suits, and unstowing and attaching the new crew escape system. On Oct. 2, the day before the mission ended, the five-man crew paid a moving tribute to the 51-L Challenger crew.

Discovery landed on Runway 17, Edwards AFB, CA, at 12:37:11 p.m. EDT on Oct. 3. Mission duration was 4 days, 1 hour, 0 minutes, and 11 seconds. Capsule Communicator Blaine Hammond Jr. welcomed the crew, saying it was "a great ending to a new beginning."

Crew. Crew members, all veteran astronauts, were Frederick H. "Rick" Hauck, commander; Richard O. Covey, pilot; and John M. "Mike" Lounge, George D. "Pinky" Nelson, and David C. Hilmers, mission specialists.

Payloads and Experiments. TDRS-C, which became TDRS-3 in orbit, and its attached Inertial Upper Stage (IUS), were deployed from Discovery's cargo bay 6 hours, 13 minutes, into the flight. The first stage of the IUS placed TDRS-3 in a transfer orbit, and the IUS second stage placed the vehicle in geosynchronous orbit on Sept. 30. TDRS-3, the second operational Tracking and Data Relay Satellite, moved into position over the Pacific Ocean south of Hawaii at 171 degrees west longitude. It joined TDRS-1 in tracking Earth-orbiting spacecraft. TDRS-B was lost in the Challenger accident. Also in the payload bay was the Orbiter Experiments Autonomous Supporting Instrumentation System (OASIS). OASIS recorded environmental data on the orbiter and the TDRS payload during various inflight phases.

All the middeck experiments were deemed to have operated or performed successfully. But there were some glitches with two of the five experiments that involved materials science. In the Protein Crystal Growth experiment, two of the 11 proteins processed did not produce crystals suitable for analysis. That includes a key enzyme in the replication of the Auto Immune Deficiency Syndrome (AIDS) virus. Also, there were some equipment problems with the Automatic Directional Solidification Furnace, an experiment to investigate the melting and solidification of various materials.

The materials processing experiments included two Shuttle Student Involvement Projects, one on titanium grain formation and the other on controlling crystal growth with a membrane. Another materials science experiment, the Physical Vapor Transport of Organic Solids, was a joint project of NASA's Office of Commercial Programs and the 3M Company.

The Tracking and Data Relay Satellite (TDRS), still attached to its Inertial Upper Stage, floats suspended in space after deployment from Discovery's cargo bay on September 29, 1988, the first day of mission STS-26. This photo was taken by a hand-held Hasselblad 70mm camera aimed through an aft flight deck window.

Three experiments were in life sciences, including one on the Aggregration of Red Blood Cells, which will help to determine if microgravity can play a beneficial role in clinical research and medical diagnostic tests. Two experiments involved atmospheric sciences and one was in communications research.

STS-27 Mission

The Space Shuttle Atlantis (OV-104) made its third flight in a classified mission for the Department of Defense (DoD). The Dec. 2, 1988 mission also was the third dedicated to the DoD. It was the 27th Space Shuttle mission. Launch was originally scheduled Dec. 1, but was postponed one day because of cloud cover and strong wind conditions. Liftoff from Pad B, Launch Complex 39, KSC, on Dec. 2 was at 9:30:34 a.m. EST. The Orbiter Atlantis touched down Dec. 6 at Runway 17, Edwards AFB, CA, at 6:36:11 p.m. EST. The total mission duration was 4 days, 9 hours, 5 minutes, and 37 seconds.

The orbiter's Thermal Protection System tiles sustained more-than-normal damage during the flight. A review panel investigating the damage found that the most probable cause was ablative insulating material from the right-hand solid rocket booster nose cap hitting the orbiter about 85 seconds into the flight.

Also, one of the main engines' turbopumps was found to be cracked after the flight.

Crew. Crew members, all military personnel, were Robert L. "Hoot" Gibson, commander; Guy S. Gardner, pilot; and Richard M. Mullane, Jerry L. Ross, and William M. Shepherd, mission specialists. Gardner and Shepherd were making their first flight.

1989

The versatility of the Space Shuttle was again demonstrated in 1989, when two planetary explorers were deployed. The launch of the Venus radar mapper, Magellan, on STS-30 in May signalled the resumption of solar system exploration and a new golden age in space science.

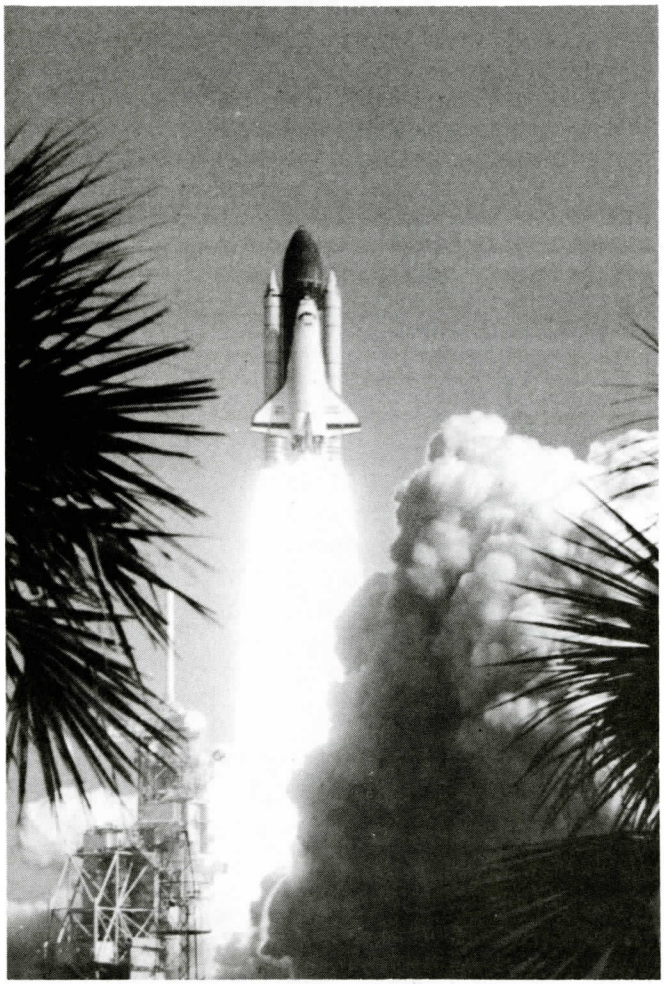
STS-29 Mission

The Space Shuttle Discovery lifted off from Pad B, Launch Complex 39, KSC, at 9:57:00 a.m. EST on March 13, 1989. Launch was originally scheduled for Feb. 18, but was postponed to allow for replacement of suspect liquid oxygen turbopumps on the three main engines. The new target date of March 11 could not be made because of the failure of a master event controller when

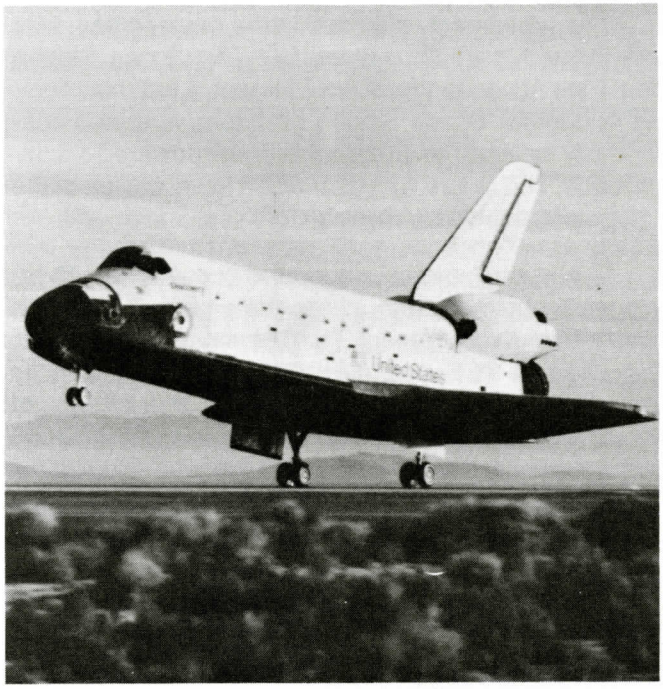
it was powered up during prelaunch checkout. The controller was replaced. On the rescheduled launch day of March 13, liftoff was held at T-9 minutes for nearly two hours because of ground fog and high upper winds. A waiver was approved for orbiter wing loads. This was the eighth flight of Discovery and the 28th Space Shuttle mission.

The primary payload was the third and final component of the Tracking and Data Relay Satellite (TDRS) constellation. The three on-orbit satellites were stationed over the equator at about 22,300 miles above Earth; two of them 130 degrees apart and a third located between them as an on-orbit spare.

On Flight Day 1, one of three cryogenic hydrogen tanks which supply the fuel cells that produce electricity exhibited erratic pressure fluctuations. It was deactivated while engineers studied the problem, and the crew was told to conserve electrical power. The tank was reactivated on Flight Day 3, March 15, and operated successfully.



Framed by Florida palm trees, the Space Shuttle Discovery makes a flawless liftoff on Mission STS-29 from Launch Pad 39B, Kennedy Space Center, on March 13, 1989.



Orbiter Discovery returns to Earth after a five-day STS-29 mission in a picture-perfect landing at Edwards Air Force Base, CA, on March 18, 1989.

Landing occurred March 18, 1989, on orbit 80, one orbit earlier than planned, in order to avoid possible excessive wind buildup expected at the landing site. Touchdown was on Runway 22 at Edwards AFB, CA, at 9:35:51 a.m. EST. Total mission duration was 4 days, 23 hours, 38 minutes, and 52 seconds.

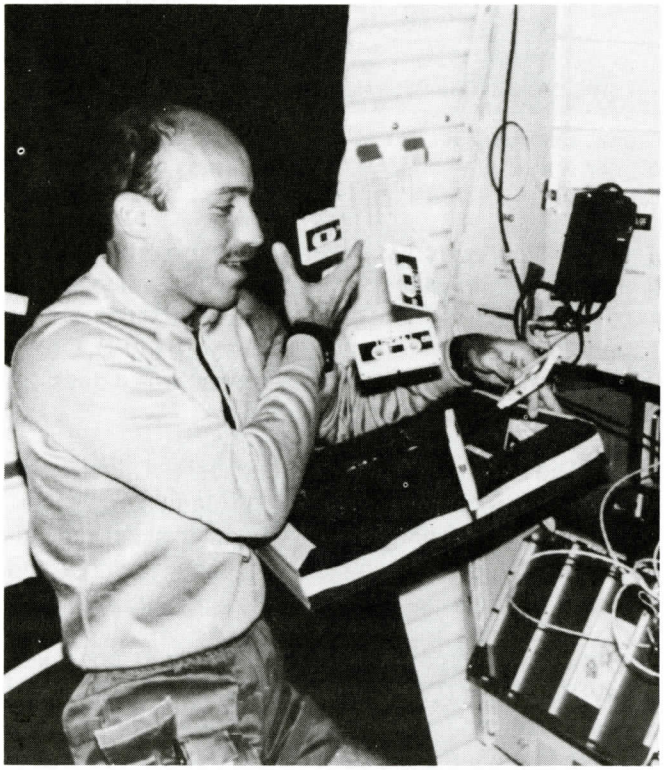
Crew. The crew members were Michael L. Coats, commander; John E. Blaha, pilot; and James F. Buchli, Robert C. Springer and John P. Bagian, mission specialists. It was the first space flight for Blaha, Springer and Bagian.

Payload and Experiments. The Tracking and Data Relay Satellite (TDRS-D), which became TDRS-4 in space, and its attached Inertial Upper Stage (IUS), were deployed from the payload bay less than six hours after launch, at 3:12 a.m. EST. First-stage orbit burn of the IUS took place an hour later, and the second burn to circularize the orbit occurred at 12 hours, 30 minutes, mission elapsed time. It was stationed at 41 degrees west longitude.

There were eight secondary payloads, including two Shuttle Student Involvement Program experiments. One student experiment, using four live rats with tiny pieces of bone removed, was to test whether the environmental effects of space flight inhibit bone healing. The other student experiment was to fly 32 chicken eggs to determine the effects of space flight on fertilized chicken embryos.

One experiment, mounted in the payload bay, was only termed "partially successful." The Space Station Heat Pipe Advanced Radiator Element, a potential cooling system for Space Station Freedom, operated continuously for less than 30 minutes under powered electrical loads. The failure was blamed on faulty design of the equipment, especially the manifold section.

All other experiments operated successfully. Crystals were obtained from all the proteins in the Protein Crystal Growth experiment. The Chromosomes and Plant Cell Division in Space (CHROMEX), a life sciences experiment, was designed to show the effects of microgravity on root development. The IMAX (70mm) camera was used to film a variety of scenes, including the effects of floods, hurricanes, fires and volcanic eruptions on Earth.



Mission specialist James P. Bagian, a physician, appears to be doing a juggling act during mission STS-29 as he tries to organize audio cassettes in the microgravity of space. Bagian conducted medical tests on his fellow crew members during the five-day mission.

STS-30 Mission

The Space Shuttle Atlantis lifted off from Pad B, Launch Complex 39, KSC, at 2:46:59 p.m. EDT on May 4, 1989. The primary payload, the Magellan spacecraft with its attached Inertial Upper Stage (IUS), was successfully deployed later that day. STS-30 was the first American planetary mission in 11 years. It was the fourth flight of the Orbiter Atlantis, and the 29th Space Shuttle mission.

Launch was originally scheduled April 28, the first day of the 31-day launch period when Earth and Venus are properly aligned. But liftoff was scrubbed at T-31 seconds because of a problem with the liquid hydrogen recirculation pump on Space Shuttle main engine No. 1 and a vapor leak in the liquid hydrogen recirculation line between the orbiter and external tank. On the rescheduled liftoff date, May 4, launch was delayed until the final five minutes of the launch window due to cloud cover and excessive crosswinds at KSC's Shuttle Landing Facility (SLF). Good landing conditions are required at the SLF in case of a Return-To-Launch-Site (RTLS) abort early in the flight.

The only major glitch during the flight occurred on May 7, with the failure of one of the four general purpose computers programmed to operate the orbiter. The crew replaced the computer, part of a redundant set, with a backup one. It was the first time a computer had been switched while in orbit. There was no impact to the crew's safety or the primary objectives of the mission, although some of the activities involved in conducting experiments had to be canceled while the crew was changing out the computer. There also was no impact to the mission when one of the three thrusters on Atlantis' aft right-hand Orbital Maneuvering System (OMS) pod failed during ascent.

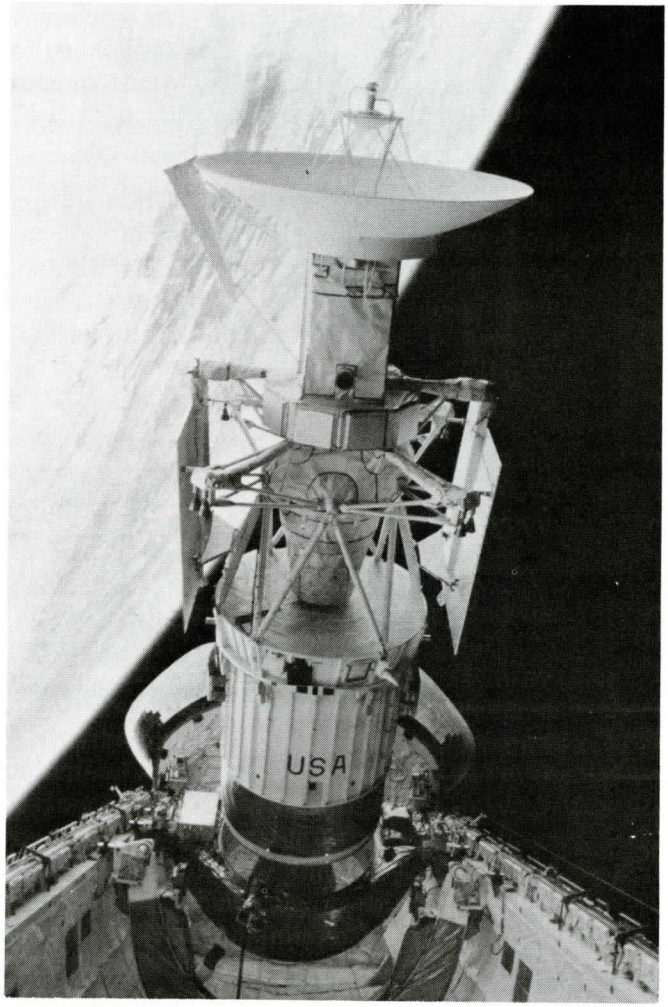
The STS-30 crew experienced several minor annoyances. A Hasselblad camera used to photograph sites on Earth had to be stowed for the remainder of the mission after a shutter stuck during the crew's third day in space. The Text and Graphics Systems (TAGS), a device to send images and graphics to the orbiter from Mission Control, had to be turned off on Flight Day 2 because of a paper jam. Commander Walker and Pilot Grabe had problems with a device used to take measurements of central venous pressure to determine the effects of microgravity on the cardiovascular system. On the second full day in space, the water dispensing system in the galley malfunctioned, causing some difficulties for the crew in preparing meals.

The crew finished the four-day flight with touchdown at Runway 22, Edwards AFB, CA, on May 8, 1989, at 3:43:27 p.m. EDT. Minutes before landing, the runway had to be switched, from 17 to 22, because of crosswinds. The mission duration was 4 days, 0 hours, 56 minutes, and 28 seconds.

Crew. The crew members were David M. Walker, commander; Ronald J. Grabe, pilot; and Mary L. Cleave, Mark C. Lee and Norman E. Thagard, mission specialists. It was Lee's first flight.

Payload and Experiments. The Magellan spacecraft was deployed from the payload bay at 6 hours, 14 minutes, into the mission. Two successive IUS propulsion burns placed the spacecraft on its trajectory to Venus about an hour later. Magellan is expected to arrive at Venus in August 1990 and begin the 243-day mission of radar mapping the planet's surface.

Three middeck experiments were included on the mission. All had flown before. Mission Specialist Cleave used a portable laptop computer to operate and monitor the Fluids Experiment Apparatus (FEA). An 8mm video camcorder flown for the first time on the Shuttle provided the opportunity for the crew to record and downlink on-orbit activities such as the FEA, which was a joint endeavor between Rockwell International and NASA. Payload bay video cameras were used to record storm systems as part of the Mesoscale Lightning Experiment. Atlantis was used as a calibration target for a third experiment involving ground-based electro-optical sensors at the Air Force Maui Optical Station in Hawaii.



The spacecraft Magellan and its attached Inertial Upper Stage are ready for deployment from the payload bay of the Orbiter Atlantis on the first day, May 4, 1989, of mission STS-30. Magellan began a 15-month journey to map the surface of Venus.

STS-28 Mission

This was the fourth classified mission dedicated to the Department of Defense. The pioneering Space Shuttle Orbiter Columbia (OV-102), the first operational reusable spaceship in NASA's fleet, lifted off from Pad B, Launch Complex 39, KSC, on Aug. 8, 1989. Liftoff time was 8:37:00 a.m. EDT. It was the 30th flight of the Space Shuttle, and the first flight of the refurbished Columbia since the 61-C mission on Jan. 12, 1986. Landing was at Edwards AFB, CA, at 9:37:08 a.m. EDT, Aug. 13. The mission lasted for 5 days, 1 hour, 0 minutes, and 8 seconds.

During the flight, the crew shut down a thruster in the reaction control system (RCS) because of indications of a leak. Also, a RCS heater malfunctioned.

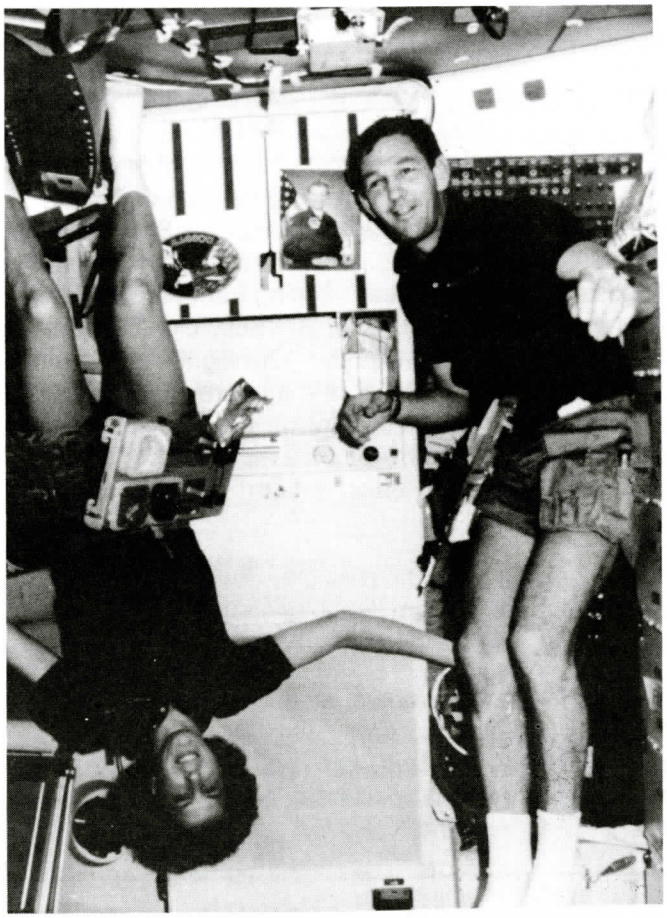
Crew. The crew members, all military personnel, were Brewster H. Shaw Jr., commander; Richard N. Richards, pilot; and Mark N. Brown, James C. Adamson and David C. Leestma, mission specialists. It was the first flight for Richards, Brown and Adamson.

STS-34 Mission

The Space Shuttle Atlantis lifted off from Pad B, Launch Complex 39, KSC, at 12:53:40 p.m. EDT on Oct. 18, 1989. It carried the Jupiter-bound Galileo spacecraft in its cargo bay. The countdown was held at T minus 5 minutes for 3 minutes and 40 seconds to update the onboard computer for a change in the Transoceanic Abort Landing (TAL) site. The TAL site was changed from Ben Guerir Air Base, Morocco, to Zaragoza Air Base, Spain, because of rain at Ben Guerir.

Launch was originally targeted for Oct. 12, the first day of the 41-day launch period during which the planets are properly aligned for a flight past Venus and Earth and, eventually, to Jupiter. Liftoff was rescheduled for Oct. 17 to replace a faulty main engine controller for Space Shuttle main engine No. 2. It was postponed again until Oct. 18 because of rainshowers within 20 miles of Kennedy Space Center's Shuttle Landing Facility. The weather conditions were in violation of the launch commit criteria for a Return-To-Launch-Site (RTLS) landing in the event of an aborted flight. It was the fifth flight of Atlantis and the 31st Space Shuttle mission.

The primary payload, the Project Galileo spacecraft with its attached Inertial Upper Stage (IUS), was successfully deployed on its journey to Jupiter. This was only



Eating for the first time in a zero gravity environment can be fun but a little tricky, as these two "rookie" astronauts discovered during the STS-34 mission. Pilot Michael J. McCulley and mission specialist Ellen S. Baker, both members of the 1984 class of NASA astronauts, are eating in a middeck area which pays tribute to their astronaut roots. The two made former astronaut Paul J. Weitz, whose portrait on the wall faces the camera, an honorary member of the 1984 class. Weitz is deputy director of Johnson Space Center in Houston, TX.

the second Shuttle flight to deploy a planetary spacecraft. (The first was STS-30 on May 4, 1989, with the Magellan spacecraft.)

NASA marks a number of firsts with STS-34. Galileo will be the first spacecraft to orbit an outer planet and to penetrate the atmosphere of an outer planet. Also, the spacecraft is scheduled to make the first extended observations of the Jovian system and first direct sampling of Jupiter's atmosphere, as well as the first asteroid flybys.

There were several anomalies during the flight, but none had a major impact on the mission. On Oct. 22, an alarm woke the crew when the gas generator fuel pump system A heaters on Auxiliary Power Unit (APU) 2 failed to recycle at the upper limits of the system. There were also some minor problems with the Flash Evaporator System for cooling the orbiter, and the cryogenic oxygen manifold valve 2, which was left closed for the rest of the mission. A Hasselblad camera jammed twice, and a spare camera had to be used.

Because of high winds predicted at the nominal landing time, the landing was moved two orbits earlier to 12:33:00 p.m. EDT on October 23. Atlantis landed at Runway 23, Edwards AFB, CA, after a mission duration of 4 days, 23 hours, 39 minutes, and 20 seconds.

Crew. The crew members were Donald E. Williams, commander; Michael J. McCulley, pilot; and Ellen S. Baker, Franklin R. Chang-Diaz and Shannon W. Lucid, mission specialists. McCulley and Baker were making their first flight.

Payload and Experiments. The first major task in orbit was deployment of the Galileo spacecraft with its attached IUS booster. Deployment occurred on schedule at 7:15 EDT, slightly more than six hours after launch, and the IUS performed flawlessly to send the spacecraft toward Venus on the first leg of its six-year journey to Jupiter. The spacecraft was injected on a Venus transfer orbit at 8:20 p.m. EDT, and separated from the IUS 47 minutes later.

Galileo will need a triple gravity assist — from Venus, Earth and then Earth again — to propel it from the inner part of the solar system to Jupiter in the outer section. Galileo has two major components, an orbiter which will examine Jupiter and its four largest moons for at least two years, and a probe which will take direct samplings of the Jovian atmosphere for up to 75 minutes before heat and pressure destroy it.

Besides the Galileo spacecraft, the payload bay held two canisters containing the Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment. SSBUV, which made its first flight on STS-34, was developed by NASA to check the calibration of the ozone sounders on free-flying satellites, and to verify the accuracy of atmospheric ozone and solar irradiance data. The experiment operated successfully.

All five middeck experiments also were deemed to have operated successfully. That includes the Polymer Morphology (PM) experiment, sponsored by the 3M Company under a joint endeavor agreement with NASA. The PM experiment was designed to observe the melting and resolidifying of different types of polymers while in orbit. Flying again was the Mesoscale Lightning Experiment to observe the visual characteristics of large-scale lightning in the upper atmosphere.

Troubleshooting by the crew was successful for a student experiment on ice crystal growth. The experiment's first activation did not produce crystals

because the supercooled water formed an ice slag on the cooling plate. The crew turned the experiment off, allowing the ice to thaw, and then redispersed the liquid. Several crystals formed.

Lucid and Baker completed the Growth Hormone Concentration and Distribution in Plants experiment on Oct. 22 by freezing samples of corn seedlings grown on orbit during the mission.

In the cabin, the crew operated the IMAX (70-millimeter) camera, last flown on STS-29 in March.

Backdropped by the blackness of space, the Galileo spacecraft and its attached Inertial Upper Stage tilt upward from a stowed position just prior to deployment from a cradle-like device in the payload bay of the Orbiter Atlantis. Earth's horizon is at left. Galileo started on a six-year journey to Jupiter.

Chang-Diaz and Baker, a medical doctor, performed a detailed supplementary objective by photographing and videotaping the veins and arteries in the retinal wall of Baker's eyeball to provide detailed measurements which might give clues about a possible relationship between cranial pressure and motion sickness. Baker also tested the effectiveness of anti-motion sickness medications in space.

On Oct. 21, Costa Rican President Dr. Oscar Arias Sanchez talked in Spanish with Chang-Diaz, a Costa Rica native, and greeted the other crew members via a special telephone linkup. Chang-Diaz also explained the mission's objectives in Spanish to listeners on the ground.

STS-33 Mission

The fifth Space Shuttle mission dedicated to the Department of Defense lifted off on Discovery from Pad B, Launch Complex 39, KSC, on Nov. 22, 1989 at 7:23:30 p.m. EST. Launch was originally scheduled Nov. 20, but was delayed because of suspect Integrated Electronics Assemblies which control ignition and separation of the Shuttle's solid rocket boosters. It was the ninth flight of Discovery and the 32nd Space Shuttle mission. STS-33 was the third night launch of the Space Shuttle program, and the first since Shuttle flights resumed in 1988. Landing was scheduled Nov. 26, but was postponed for a day because of strong winds at the landing site.

Discovery landed on a concrete runway at Edwards AFB, CA, on Nov. 27 at 7:30:16 p.m. EST, after a mission duration of 5 days, 0 hours, 6 minutes, and 49 seconds.

Crew. The five-member crew included Frederick D. Gregory, commander; John E. Blaha, pilot; and F. Story Musgrave, Manley L. Carter Jr., and Kathryn C. Thornton, mission specialists. It was the first space flight for Carter and Thornton.

1990

The year 1990 was truly one of triumphs and challenges in America's Space Shuttle program. Elusive leaks in two of the three orbiters halted liftoffs for more than five months, but NASA/contractor teams of "leak busters" resolved the problems quickly enough for six missions to be launched in 1990. Focus on the space sciences continued, with half of the flights concentrating on solar system exploration and observation. Both launch pads at Kennedy were active—each supported three Shuttle liftoffs in 1990. The year also was marked by the first end-of-mission landing of an orbiter at KSC since 1985, necessitated by poor weather at the West Coast site.

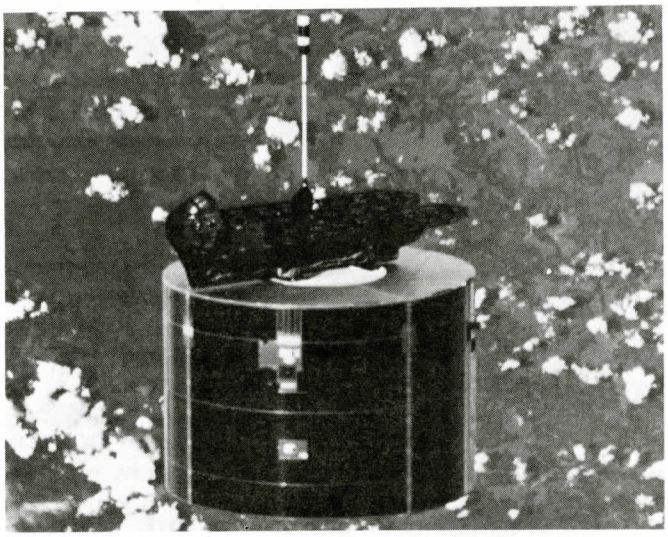
STS-32 Mission

The Space Shuttle Columbia (OV-102) lifted off from Pad A, Launch Complex 39, KSC, at 7:35:00 a.m. EST on Jan. 9, 1990. The two primary objectives of the mission were retrieval of the bus-sized Long Duration Exposure Facility and deployment of the SYNCOM IV-5 geosyn-

chronous communications satellite. Both were successfully accomplished by Jan. 12, only three days into the mission.

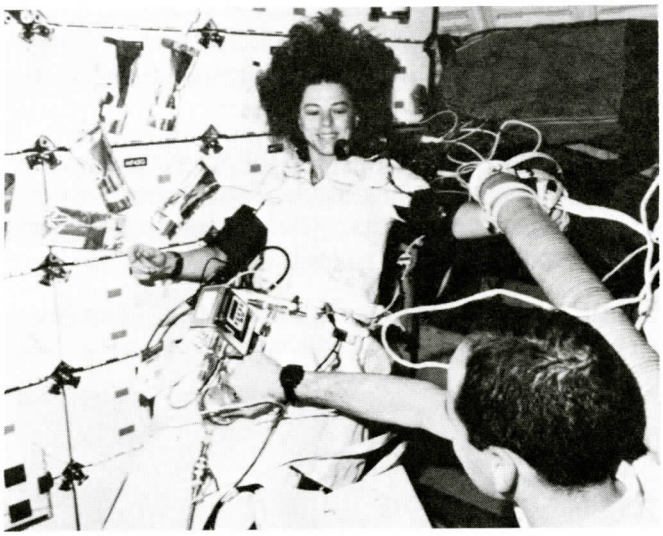
Launch was scheduled for Dec. 18, 1989, but was postponed to Jan. 8, 1990, to complete testing and validation of the newly refurbished launch pad, to perform maintenance on the Launch Processing System and to permit NASA employees and contractors to take off during the holidays. Liftoff was delayed one day, until Jan. 9, because of cloud cover at KSC. The 33rd Space Shuttle mission was the ninth flight of Columbia, the first operational orbiter in the fleet. It was the first Shuttle launch from Pad A since STS 61-C on Jan. 12, 1986.

STS-32 was the longest Space Shuttle flight to date with a mission duration of 10 days, 21 hours, 0 minutes, and 37 seconds. Columbia also set the previous record of time in space during the 10-day STS-9 mission in 1983. NASA planned the extended mission to gather data on the crew members' exposure to long periods of zero gravity and its effects on landing the orbiter. STS-32 was the first in a series of planned missions to extend the mission duration of the orbiter.



The SYNCOM IV-5 satellite, referred to as LEASAT 5 when deployed, orbits high above Earth after it was released from Columbia's payload bay on Jan. 10, 1990. The communications satellite was passing over Zaire when this photo was taken by the STS-32 crew.

Some minor annoyances plagued the crew, but did not significantly impact the mission. A crew cabin alarm was triggered three times by an avionics bay smoke detector, the result of a circuit problem and not a fire. The Text and Graphics Systems (TAGS) used to fax messages to the crew did not work for several days, and the astronauts had to receive messages from the teleprinter until the problem was fixed. The crew also had to vacuum up water after one of two humidity separators in the crew cabin sprung a leak. An apparently erroneous transmission of data caused the orbiter's six vernier thrusters to



Mission specialist G. David Low, right foreground, monitors fellow STS-32 crew member and mission specialist Bonnie J. Dunbar in the collapsible lower body negative pressure unit on the middeck of the Orbiter Columbia.

fire, but the STS-32 commander quickly corrected Columbia's attitude by taking manual control.

Columbia was scheduled to land at Edwards Air Force Base, CA, on Jan. 19. Landing was postponed twice that day because expected dense fog would violate flight rules. The orbiter touched down on concrete Runway 22, Edwards AFB, at 4:35:37 a.m. EST on Jan. 20.

Crew. The crew members were Daniel C. Brandenstein, commander; James D. Wetherbee, pilot; and Bonnie J. Dunbar, Marsha S. Ivins and G. David Low, mission specialists. Wetherbee, Ivins and Low made their maiden flights. On Jan. 19, Brandenstein broke the previous record by logging the most number of hours aboard a Space Shuttle. The record of 565 hours and 48 minutes had been set by Robert Crippen. Also during STS-32, Dunbar broke the record of the most hours flown in space by an American woman.

Payloads and Experiments. Deployment of the SYNCOM satellite on Flight Day 2, less than 25 hours into the mission, was the first major milestone of STS-32. The deployment by Mission Specialists Low and Dunbar went smoothly at 8:18 a.m. EST, Jan. 10. SYNCOM was designed exclusively for launch from the orbiter, using the "frisbee" or rollout method of deployment. It was ejected from the cargo bay when locking pins at four contact points were retracted, and an explosive device released a spring. The satellite's Minuteman III solid-fuel perigee motor ignited about 35 minutes later, propelling SYNCOM toward its orbital high point. Successive burns by two liquid-fueled engines circularized the orbit, aligned the flight path with the equator and established a geosynchronous altitude for SYNCOM IV-5, referred to as LEASAT 5 when deployed.

This satellite completes the worldwide LEASAT satellite communications system, which is owned and operated by Hughes Communications Inc., and leased to the Department of Defense, with the U.S. Navy acting as executive agent. The system of four operational satellites and associated ground facilities provides worldwide, high-priority communications among aircraft, ships, submarines and land-based stations of the U.S. military services.

Retrieval of the Long Duration Exposure Facility (LDEF) was the other major task of the mission. LDEF was originally intended to remain in space for about a year after it was deployed April 7, 1984, on STS 41-C. Scheduling changes and the 51-L accident delayed the retrieval mission. The orbit of LDEF had been decaying, and it was in danger of being destroyed by re-entering Earth's atmosphere.

On Jan. 12, commander Brandenstein piloted the orbiter within reach. Mission specialist Dunbar, looking out the rear window of Columbia, used the 50-foot Remote Manipulator System arm to grapple the 21,400-pound satellite at 10:16 a.m. EST. Mission specialist Ivins then performed a detailed photographic survey of the 12-sided cylinder before LDEF was berthed in Columbia's payload bay for the remainder of the mission.

STS-32 Commander Daniel C. Brandenstein celebrated his 47th birthday on Jan. 17, 1990, aboard the Space Shuttle Columbia with an inflatable — not edible — cake. Two days later, Brandenstein broke the previous record of the most hours in flight on a Space Shuttle. STS-32 was his third space flight.

LDEF was returned to Kennedy Space Center, where the 57 experiments it contained were removed, examined and shipped to the Principal Investigators for detailed analysis. The delay in the retrieval mission proved beneficial to many involved scientists and engineers, who gathered much data on the effects of long-term space exposure on various materials. This information will be very valuable in the design and operation of Space Station Freedom. And the tomato seeds contained in the Space Exposed Experiment Developed for Students (SEEDS) already have been planted by numerous student groups, and produced healthy fruit.

Seven middeck experiments, all of which had flown before in some version, were performed during the flight. A few glitches were reported. The refrigeration for the Protein Crystal Growth (PCG) experiment was inadvertently cut off, but later restored, and there was a loss of pressure, possibly from a crack, in the glass tube holding one of the samples for the Fluids Experiment Apparatus (FEA). The FEA was still declared a success. Distortion was reported on half of the screen used by the crew as a monitor for the American Flight Echocardiograph experiment, a medical ultrasonic imaging system.

STS-36 Mission

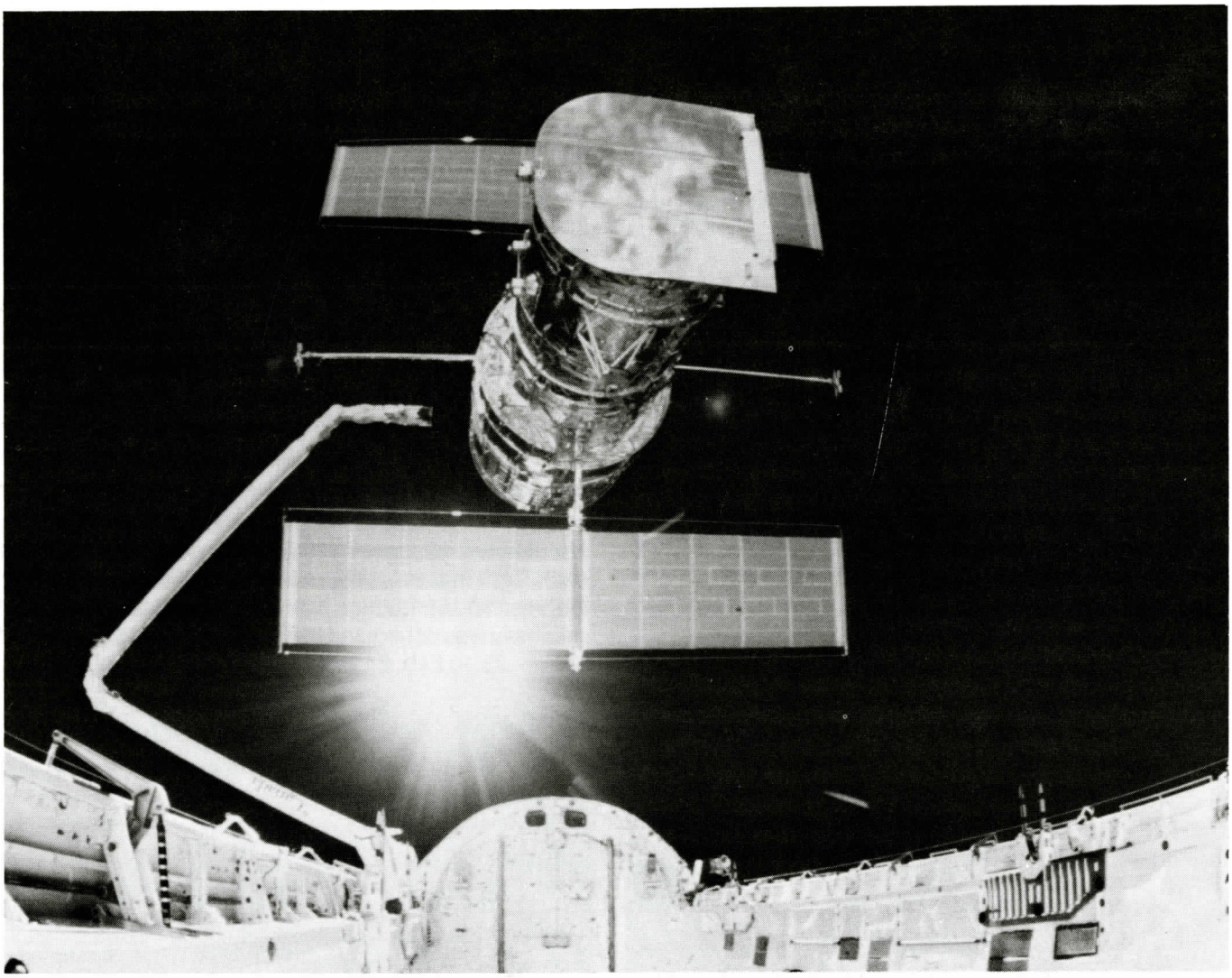
The Space Shuttle Atlantis (OV-104), which in 1985 became the youngest orbiter to join the fleet, made its sixth flight in a classified mission for the Department of Defense (DoD). Launch was postponed five times. Liftoff originally was scheduled for Feb. 22, but was postponed to Feb. 23, to Feb. 24 and then to Feb. 25 because of the illness of the crew commander and unfavorable weather. Commander John O. Creighton, suffering from an upper respiratory tract infection, was cleared for flight on Feb. 23. It was the first time a manned space mission was affected by the illness of a crew member since Apollo 13 in 1970 when three astronauts were exposed to the measles.

The STS-36 launch again was scrubbed on Feb. 25 with less than 2 minutes to liftoff because of the malfunction of a range safety ground computer. Unfavorable weather again delayed the launch on Feb. 26. Rain showers and clouds on Feb. 28 postponed liftoff for a couple of hours, but Atlantis finally took off from Pad A, Launch Complex 39, KSC, at 2:50:22 a.m. EST. The six-day delay involved only three tanking operations, for the attempts on Feb. 25 and 26 and launch on Feb. 28. It was the 34th Space Shuttle mission since flight operations began in 1981, and the sixth dedicated DoD flight.

Atlantis touched down on lakebed Runway 23, Edwards Air Force Base, CA, on March 4 at 1:08:44 p.m. EST. The mission duration was 4 days, 10 hours, 18 minutes, and 22 seconds.

After landing, engineers reported the presence of a thin film of hydraulic fluid coating the interior of the aft engine compartment. A leak in a hydraulic system hose for Auxiliary Power Unit (APU) No. 2 was blamed.

Crew. Crew members, all military personnel, were John O. Creighton, commander; John H. Casper, pilot; and David C. Hilmers, Richard M. Mullane and Pierre J. Thuot, mission specialists. Casper and Thuot made their first flight.



The Hubble Space Telescope, the first of the planned four Great Observatories, embarks on its 15-year mission to explore the universe. The orbiting observatory was just released from the Space Shuttle's payload bay by the Remote Manipulator System arm, seen in background at left.

STS-31 Mission

The Space Shuttle Discovery (OV-103) was launched on Mission STS-31 from Pad B, Launch Complex 39, KSC, at 8:33:51 a.m. EDT on April 24, 1990. It carried in its payload bay the long-anticipated Hubble Space Telescope, first of the planned four Great Observatories. The telescope was successfully deployed on Flight Day 2, and has already provided valuable data and a closer look at the universe than ever before. The beginning of its 15-year odyssey was marred by the discovery of a spherical aberration in its primary mirror less than a month into the orbital checkout period.

Liftoff was targeted for April 18, and then moved ahead to April 12 and finally to April 10 following the Flight Readiness Review (FRR). It was the first time a launch date set at the FRR was earlier than the one shown on previous schedules.

The launch on April 10 was scrubbed at T-4 minutes because of a faulty valve in Auxiliary Power Unit (APU) No. 1. It was rescheduled for April 24 after the APU was replaced and Hubble's batteries were recharged. Liftoff was delayed almost 3 minutes that day while ground controllers worked a problem with the liquid oxygen fill-and-drain valve in the orbiter's main propulsion system. The countdown resumed at the T-31 second mark after it was verified that the valve was closed. STS-31 was the 10th mission for Discovery and the 35th flight of the Space Shuttle program.

The Orbiter Discovery landed on concrete Runway 22, Edwards Air Force Base, CA, at 9:49:57 a.m. EDT on April 29, 1990. The mission duration was 5 days, 1 hour, 16 minutes, and 6 seconds. This was the first time newly designed carbon brakes on the main landing gear were used. The brake and landing gear modifications would eventually permit NASA to resume routine end-of-mission landings at KSC.

Crew. Crew members, all veterans of space flight, were Loren J. Shriver, commander; Charles F. Bolden Jr., pilot; and Steven A. Hawley, Bruce McCandless II and Kathryn D. Sullivan, mission specialists.

Payloads and Experiments. The deployment of Hubble began on April 25 shortly after 7 a.m. EDT when mission specialist Steven A. Hawley grappled Hubble with the Remote Manipulator System (RMS) arm. The telescope was finally freed from the cargo bay to begin its 15-year mission at 3:38 p.m. EDT. One of the solar array panels, which keep the nickel hydrogen batteries charged, unfurled without a hitch. But the starboard side array initially would not extend. It was finally unfurled, and Hawley released the RMS arm's grip, sending the telescope into orbit one revolution later than planned. Mission specialists McCandless and Sullivan were prepared for an extravehicular activity (EVA) to troubleshoot any problems, but it did not prove necessary.

Scientists are confident that they can implement measures to correct for the aberration in the main mirror, and enable Hubble to carry out most of its planned observations during the next decade and a half. Even before the mirror flaw was discovered, NASA planned future flights to replace parts of the telescope with second-generation instruments. A Shuttle mission in 1993 is scheduled for a rendezvous with Hubble.

In the meantime, Hubble is still capable of seeing objects in visible light more clearly than ground-based telescopes. Computer restoration already has reduced some of the effects of the spherical aberration. A more minor problem, a slight vibration as Hubble moves from sunlight into darkness or darkness into sunlight, also developed during activation and fine-tuning of the telescope.

The STS-31 mission included other payloads or experiments which occupied some of the astronauts' time. Crew members had unique views of the Earth at the mission's altitude of about 380 statute miles, the highest in Space Shuttle history, and filmed many of the sights using 70-millimeter IMAX cameras, one in the payload bay and another in the middeck area.

Investigation of Arc and Ion Behavior in Microgravity was a student experiment designed to study the effect of weightlessness on electrical arcs. During the mission, astronaut Bolden narrated a video playback of the experiment.

About 60 different Protein Crystal Growth experiments with 12 proteins were conducted during the mission to provide information on improving food production and biomedical technology. When flown before, this payload has furnished high-quality crystals developed in the microgravity of space; STS-31 was the fourth flight of the experiment since return-to-flight in 1988.

STS-41 Mission

The Orbiter Discovery (OV-103) made the first Space Shuttle launch in more than five months when it soared into space on STS-41 on Oct. 6, 1990, carrying the planetary spacecraft Ulysses. The 7:47:15 a.m. EDT liftoff was from Pad B, Launch Complex 39, KSC, only 12 minutes after the launch window opened that day. Hydrogen fuel leaks on the other two orbiters, Columbia and Atlantis, grounded those vehicles while engineers pinpointed the problems and corrected them. Discovery, the third member of the orbiter fleet, did not have any leaks.

The primary payload was the Ulysses spacecraft with its attached two-stage Inertial Upper Stage (IUS) and the PAM-S, a mission-specific modified version of the standard Payload Assist Module. Ulysses was successfully deployed to begin its five-year journey to explore the uncharted regions of the Sun's north and south poles. The four-day flight of STS-41 was the 11th mission for Discovery and 36th of the Space Shuttle program. No major system anomalies were reported during the flight.

Ulysses is the third interplanetary explorer launched by the Space Shuttle. It followed Magellan, which is mapping the surface of Venus, and the Jupiter-bound Galileo spacecraft, both of which were deployed in 1989. Ulysses is a cooperative venture between NASA and the European Space Agency.

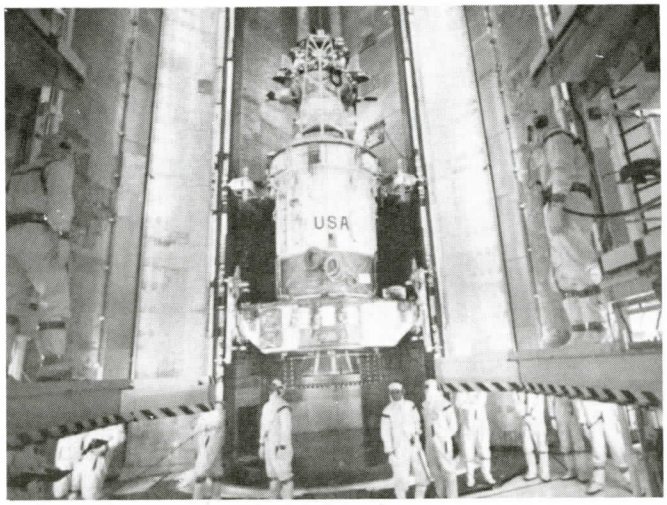
Discovery touched down on concrete Runway 22, Edwards AFB, CA, at 9:57:18 a.m. EDT on Oct. 10, after a mission duration of 4 days, 2 hours, 10 minutes, and 3 seconds.

Crew. Crew members, all military personnel, were Richard N. Richards, commander; Robert D. Cabana, pilot; and William M. Shepherd, Bruce E. Melnick and Thomas D. Akers, mission specialists. Making their first flight were Cabana, Melnick and Akers.

Payloads and Experiments. The spacecraft Ulysses and its upper-stage engines were released from Discovery's payload bay on Oct. 6, 1990, at 1:48 p.m. EDT, almost exactly six hours after liftoff. This was the first time a three-stage booster system was used on a Shuttle payload. It was necessary to give Ulysses the power and speed required to place the spacecraft on a trajectory outside the ecliptic plane, the imaginary extension of the Sun's equator around which all the planets orbit.

The two stages of the IUS fired within minutes of each other, the first about 65 minutes after deployment. The single-stage PAM-S attached to Ulysses ignited a few minutes later, giving the spacecraft the fastest departure speed of any man-made craft leaving Earth, at a geocentric velocity of more than 34,000 miles per hour. The next day, Oct. 7, Ulysses' radial boom with sensors for science instruments was deployed, slowing the

spacecraft's spin rate. Ulysses is powered by a radioisotope thermoelectric generator (RTG). The approximately 800-pound spacecraft will need a gravitational assist from Jupiter in 1992 to sling it on a course perpendicular to the ecliptic, where it will explore the uncharted areas of the Sun's north and south poles and make in situ measurements. Its first high-latitude polar pass is scheduled in 1994.



Workers at Launch Pad 39B prepare to transfer Ulysses and its attached boosters into the payload changeout room. Ulysses will then be installed in the orbiter cargo bay.

One of the secondary experiments, operating out of the cargo bay, was the recently added INTELSAT Solar Array Coupon (ISAC). ISAC contained samples of materials like that on the solar arrays of a stranded INTELSAT VI satellite, launched in March 1990 on a Titan III. The samples were flown on the Remote Manipulator System (RMS) arm. The experiment was designed to determine whether the solar arrays have been impaired by atomic oxygen while the satellite has been stranded in a low orbit. A Space Shuttle crew is scheduled to rescue the satellite in 1992.

Also mounted in the payload bay was the Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment for in-orbit calibration of ozone-measuring instruments flown on free-flying satellites. This experiment flew once before, on STS-34 in October 1989.

Mission Specialists Shepherd and Melnick operated the Voice Command System, a voice recognition device for operation of the closed-circuit television system for the payload bay and aft flight deck. The astronauts, particularly Shepherd, had some difficulties with the system recognizing all their commands. But they reported success with their third and final session with the experiment.

Among the other middeck payloads activated by the crew were the Chromosome and Plant Cell Division Experiment (CHROMEX) to study plant growth in microgravity; the Physiological Systems Experiment to determine the effects of a proprietary protein on animal physiological systems in microgravity; the Solid Surface Combustion Experiment using a combustion chamber to collect data on the spread of fire over the surfaces of fuels in microgravity; and a student experiment called Convection in Zero Gravity.

STS-38 Mission

STS-38 was both the seventh flight of the Orbiter Atlantis and the seventh and final classified mission dedicated to the Department of Defense. It was the 37th Space Shuttle mission.

Liftoff occurred Nov. 15 at 6:48:15 p.m. EST from Pad A, Launch Complex 39, KSC. Launch was originally scheduled in July. A liquid hydrogen leak discovered on the Orbiter Columbia during the STS-35 launch countdown prompted officials to schedule precautionary mini-tanking tests on Atlantis on June 29, July 13 and July 25. The tests confirmed a hydrogen fuel leak on the external tank side of the orbiter/tank 17-inch quick-disconnect umbilical.

After officials determined that an on-the-pad fix was not possible, the Space Shuttle Atlantis was rolled back to the Vehicle Assembly Building (VAB) on Aug. 9. While parked outside the VAB during rollback, Atlantis sustained minor hail damage to its Thermal Protection System tiles. It was demated inside the VAB, and transferred to the Orbiter Processing Facility for repairs. The orbiter was rolled back to the VAB on Oct. 2 for mating with a new external tank and two solid rocket boosters. During hoisting operations, a platform beam that had been left in the vehicle's aft compartment fell and caused minor damage, which was repaired. Atlantis rolled out again to Pad A, Launch Complex 39, KSC, on Oct. 12. A fourth and final tanking test on Oct. 24 showed no excessive hydrogen or oxygen leakage, and subsequently a new launch date of Nov. 9 was set. The U.S. Air Force then decided to delay launch because of anomalies discovered during testing of the classified cargo, and liftoff was rescheduled for Nov. 15.

Landing was scheduled on Nov. 19 at Edwards Air Force Base, CA, but the orbiter was waved off because of unacceptable crosswinds on the desert runway. Continued adverse conditions in California threatened to delay landing a second day, and officials decided to shift landing to Kennedy Space Center. Atlantis landed on concrete Runway 33 at KSC's Shuttle Landing Facility on Nov. 20 at 4:42:42 p.m. EST. Mission duration was 4 days, 21 hours, 54 minutes, and 27 seconds. It was the sixth landing at KSC for the Space Shuttle program, but the first since Discovery in April 1985. It also was the first KSC landing for the Orbiter Atlantis.

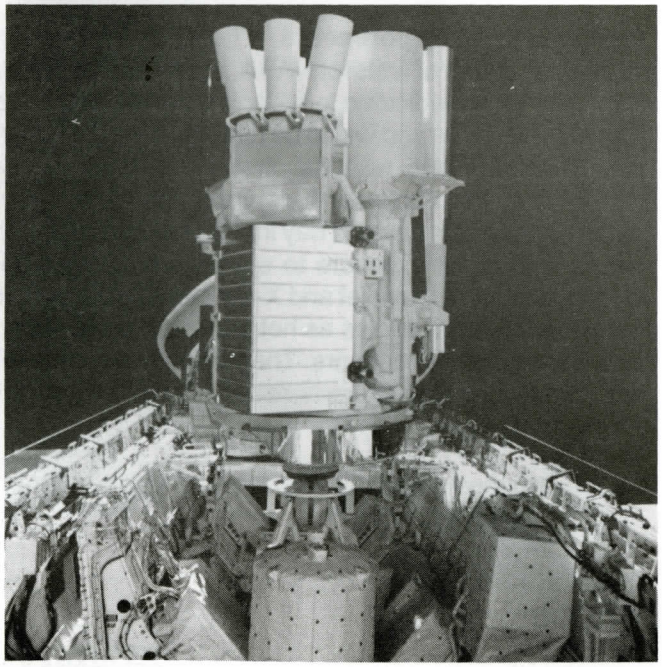
During the mission, two of Atlantis' windows were damaged and later had to be replaced.

Crew. Crew members were Richard O. Covey, commander; Frank L. Culbertson Jr., pilot; and Charles D. Gemar, Carl J. Meade and Robert C. Springer, mission specialists. The space rookies were Culbertson, Gemar and Meade.

STS-35 Mission

The Space Shuttle Columbia lifted off from Pad B, Launch Complex 39, KSC, at 1:49:01 EST on Dec. 2, 1990. It carried the astronomical observatory, Astro-1, in its cargo bay. Launch was delayed about 21 minutes at the T-9 minute mark while U.S. Air Force range safety officers evaluated a nearby cloud deck that restricted visibility for the 10th flight of the Orbiter Columbia and 38th Space Shuttle mission.

Liftoff was scrubbed four times, three times because of leaks and once because of a payload problem. STS-35 originally was targeted for a May 16 launch from Pad 39A, but mission managers announced a delay to fix a problem in Columbia's No. 1 freon coolant loop. The mission was then scheduled for a May 30 launch, but liftoff was scrubbed during propellant loading after high concentrations of hydrogen gas were detected in the orbiter's aft compartment and the 17-inch hydrogen fuel line's quick-release disconnect assembly. The disconnect assemblies on both the external tank and orbiter sides were replaced. (The assembly on the orbiter side was taken from Endeavour, the new orbiter being built by Rockwell International Corp. in California.)



The Astro-1 instruments are silhouetted against the backdrop of space in this view from Columbia's aft flight deck windows during STS-35.

A mini-tanking test on June 6 confirmed the leak in the 17-inch umbilical. Columbia was rolled back to the Vehicle Assembly Building (VAB), demated from the solid rocket boosters and external tank, and brought to the Orbiter Processing Facility for repairs. It was returned to Pad A Aug. 9 for a launch targeted Sept. 1. That liftoff was postponed because of a problem in the avionics component of the Broad Band X-Ray Telescope (BBXRT), one of four telescopes which comprise the Astro-1 observatory.

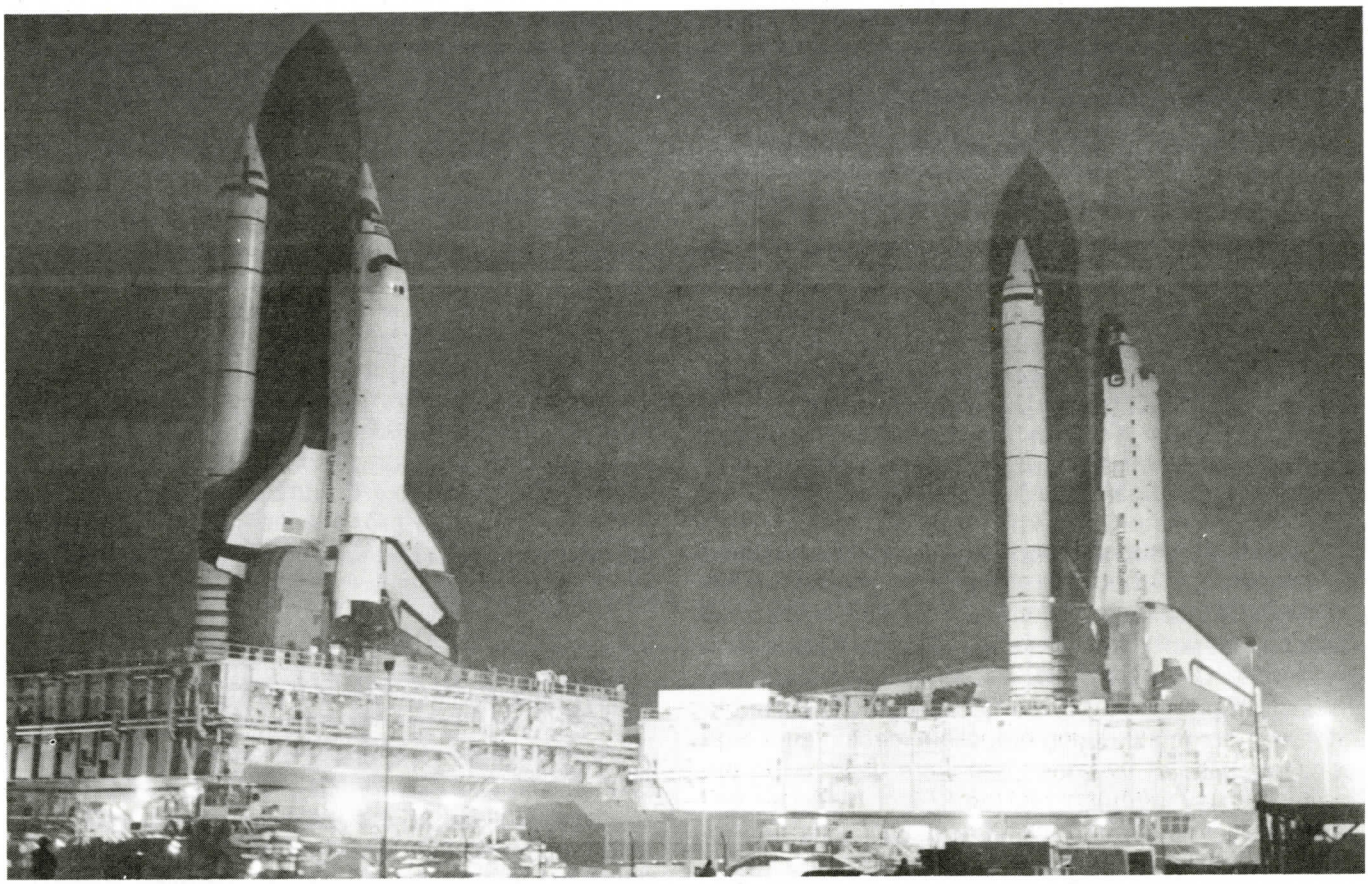
Subsequent launch attempts on Sept. 6 and Sept. 18 were delayed when hydrogen leaks in the aft compartment persisted. During that time, managers decided to replace three hydrogen recirculation pumps in the aft compartment and a damaged cover seal in the Engine No. 3 hydrogen prevalve. Columbia was then transferred to Pad B to make room for Atlantis. Tropical Storm Klaus forced a rollback to the VAB on Oct. 9, and the Shuttle was transferred again to Pad B five days later.

After trouble shooting and repairs by a special team of experts, a tanking test Oct. 30 on Columbia showed leakage well within acceptable limits.

The STS-35 mission was marred by equipment failures, but was nevertheless considered a scientific success because of the large volume of high-quality astronomical data gathered during the nearly nine-day mission. Problems began early in the mission with the operation of the Instrument Pointing System (IPS) and calibration of three star trackers. Less than 10 hours into the flight, one of the two Data Display Units (DDUs) failed, and astronauts had to manually point the three ultraviolet telescopes which are part of the Astro-1 observatory. The two computer units provide the primary data path from the Astro-1 payload to the flight crew. The fourth instrument, the X-ray telescope, was on a separate pointing system and was unaffected by the DDU failure. Science operations also were interrupted briefly four days into the mission when an orbiter vernier thruster failed, and "hot fires" were required to clear the system. This required the four telescopes to be safed for more than an hour to prevent possible contamination.

The second DDU shut down on Dec. 6, and mission managers and engineers had to control the three ultraviolet telescopes from the ground, with fine-tuning by the astronaut/astronomer crew members. The seven-member crew divided into two shifts and manned the observatory around the clock. Even with technical problems, Astro-1 telescopes observed 68 percent of the more than 200 planned celestial targets, and met 30 to 40 percent of the instruments' scientific objectives.

Also, a clogged line in Columbia's wastewater dump system threatened to end the mission early, but crew members managed to store the wastes on board instead of dumping them in space.



Two ships passing in the night — The majestic Space Shuttle Columbia, at left, passes within yards of its sister ship, the Space Shuttle Atlantis, outside KSC's Vehicle Assembly Building (VAB) in the early morning hours of Aug. 9, 1990. Columbia was on its way to Launch Pad 39A for STS-35, and Atlantis was parked outside the VAB after rollback from 39A for repair of a hydrogen fuel leak. Fuel leaks were discovered in two of the three orbiters in 1990.

A highlight of the mission was a conversation via satellite between the crew and two top world diplomats, U.S. Secretary of State James Baker and Soviet Foreign Minister Eduard Shevardnadze, who were visiting the Johnson Space Center in Houston, Texas. But the crew missed a planned radio link with cosmonauts aboard the Soviet Space Station Mir.

The mission ended about a day early, on Dec. 11 at 12:54:08 a.m. EST, but not because of equipment problems. Managers decided to bring the orbiter — heavier than usual because of its nearly 30,000-pound Astro-1 payload — home early because of rain and high winds predicted at the California landing site. Columbia landed on concrete Runway 22, Edwards Air Force Base, CA, after a mission duration of 8 days, 23 hours, 5 minutes, and 7 seconds.

Crew. The seven crew members were Vance D. Brand, commander; Guy S. Gardner, pilot; John M. "Mike" Lounge, Jeffrey A. Hoffman and Robert A.R. Parker, mission specialists; and Ronald A. Parise and Samuel T. Durrance, payload specialists. Parise and Durrance made their first flight.

Payloads and Experiments. The STS-35 mission marked a number of firsts for NASA. It was the first Space Shuttle mission dedicated to a single scientific discipline — astrophysics — and first to be directed by three NASA installations. It also was the first since 1985 to use elements of the European-built Spacelab, which converted Columbia's payload bay into an on-orbit research center with direct exposure to space. Astro-1 was designed to detect ultraviolet and X-ray radiation from such energetic celestial bodies as hot stars, galaxies, supernova remnants and quasars. The payload was returned to Kennedy Space Center where it was removed from the orbiter and stored.

During the mission, NASA debuted a pilot program, Space Classroom, in which astronauts conduct lessons in mathematics, science and technology from space. Students on the ground can ask questions and talk with crew members.

The Shuttle Amateur Radio Experiment (SAREX-II) demonstrated the capability of packet (digital transmission) radio to collect and disseminate a high volume of messages to and from orbit.